VOLUME 2

FINAL REPORT OF THE SPACE SHUTTLE PAYLOAD PLANNING WORKING GROUPS

ATMOSPHERIC & SPACE PHYSICS

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NATIONAL AERONAUTICS & SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND 20771

GLOSSARY

Abbreviation	Description
APL	Applied Physics Laboratory (Johns Hopkins Univ.)
ASF	Atmospheric Science Facility
ATS	Applications Technology Satellite
COSPAR	Committee on Space Research
ESRO	European Space Research Organization
GEOS	Scientific Geostationary Satellite (ESRO)
GSFC	Goddard Space Flight Center
IAGA	International Association of Geophysics and Aeronomy
IME	International Magnetospheric Explorer
IMP-J	Interplanetary Monitoring Platform-J
IMS	International Magnetospheric Study
ISIS	International Satellite for Ionospheric Studies
JSC	Lyndon B. Johnson Space Center (formerly MSC)
LaRC	Langley Research Center
MAMOS	Magnetosphere and Auroral Manned Observatory System
MPI-Germany	Max Planck Institute
MSC	Manned Spacecraft Center (Houston), now JSC
MSFC	Manned Space Flight Center
NAS	National Academy of Sciences
NIMBUS	Meteorological Observation Satellite
NOAA	National Oceanic and Atmospheric Administration
OGO	Orbiting Geophysical Observatory
PPEPL	Plasma Physics and Environmental Perturbation Laboratory
SAR	Stable Auroral Red (Arcs)
SSB	Space Science Board
SST	Supersonic Transport
TRW/STL	Thompson-Ramo-Wooldridge Space Technology Laboratories
URSI	International Union of Radio Science

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Atmospheric & Space Physics

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FOREWORD*

In January 1972 the United States decided to develop a new space transportation system, based on a reusable space shuttle, to replace the present expendable system.

By January 1973 planning had progressed to the point that through the European Space Research Organization (ESRO) several European nations decided to develop a Space Laboratory consisting of a manned laboratory and a pallet for remotely operated experiments to be used with the shuttle transportation system when it becomes operational in 1980.

In order to better understand the requirements which the space transportation must meet in the 80's and beyond; to provide guidance for the design and development of the shuttle and the spacelab; and most importantly, to plan a space science and applications program for the 80's to exploit the potential of the shuttle and the spacelab, the United States and Europe have actively begun to plan their space programs for the period 1978-1985, the period of transition from the expendable system to the reusable system. This includes planning for all possible modes of shuttle utilization including launching automated spacecraft, servicing spacecraft, and serving as a base for observations. The latter is referred to as the sortie mode. The first step in sortie mode planning was the Space Shuttle Sortie Workshop for NASA scientists and technologists held at the Goddard Space Flight Center during the week of July 31 to August 4, 1972. For the purposes of that workshop, shuttle sortie missions were defined as including those shuttle missions which employ observations or operations (1) from the shuttle itself, (2) with subsatellites of the shuttle, or (3) with shuttle deployed automated spacecraft having unattended lifetimes of less than about half a year.

In general the workshop was directed towards the education of selected scientific and technical personnel within NASA on the basic capabilities of the shuttle sortie mode and the further definition of how the sortie mode of operation could benefit particular disciplines. The specific workshop objectives included:

- Informing potential NASA users of the present sortie mode characteristics and capabilities
- Informing shuttle developers of user desires and requirements
- An initial assessment of the potential role of the sortie mode in each of the several NASA discipline programs
- The identification of specific sortie missions with their characteristics and requirements

*Reprinted from the volume entitled "Executive Summaries".

- The identification of the policies and procedures which must be changed or instituted to fully exploit the potential of the sortie mode
- Determining the next series of steps required to plan and implement sortie mode missions.

To accomplish these objectives 15 discipline working groups were established. The individual groups covered essentially all the space sciences, applications, technologies, and life sciences. In order to encourage dialogue between the users and the developers attendance was limited to about 200 individuals. The proceedings were, however, promptly published and widely distributed. From these proceedings it is apparent that the workshop met its specific objectives. It also generated a spirit of cooperation and enthusiasm among the participants.

The next step was to broaden the membership of the working groups to include non-NASA users and to consider all modes of use of the shuttle. To implement both objectives the working group memberships were expanded in the fall of 1972. At this time some of the working groups were combined where there was appreciable overlap. This resulted in the establishment of the 10 discipline working groups given in Attachment A. In addition European scientists and official representatives of ESRO were added to the working groups. The specific objectives of these working groups were to:

- Review the findings of the GSFC workshop with the working groups
- Identify as far as possible the missions (by mode) that will be required to meet the discipline objectives for the period 1978 to 1985
- Identify any new requirements or any modifications to the requirements in the GSFC report for the shuttle and sortie systems
- Identify the systems and subsystems that must be developed to meet the discipline objectives and indicate their priority and/or the sequence in which they should be developed
- Identify any new supporting research and technology activity which needs to be initiated
- Identify any changes in existing procedures or any new policies or procedures which are required in order to exploit the full potential of the shuttle for science, exploration and applications, and provide the easiest and widest possible involvement of competent scientists in space science
- Prepare cost estimates, development schedules and priority ranking for initial two or three missions

In order to keep this planning activity in phase with the shuttle system planning the initial reports from these groups were scheduled to be made available by the spring of 1973. It was also felt necessary that the individual working group activities be coordinated both between the groups and with the shuttle system planning. As a result, the steering group given in Attachment B was established.

Early in 1973, NASA and the National Academy of Sciences jointly decided that it would be appropriate for a special summer study to review the plans for shuttle utilization in the science disciplines. This summer study has now been scheduled for July 1973. It is anticipated that the results of the working group activities to date will form a significant input into this study.

In the following sections of the summary document are the executive summaries of each of the working group reports. While these give a general picture of the shuttle utilization plan, the specific plan in each discipline area can best be obtained from the full report of that working group. Each working group report has been printed as a separate volume in this publication so that individuals can select those in which they are particularly interested.

From these working group reports it is apparent that an appreciable effort has been made to exploit the full capability of the shuttle. It is, however, also apparent that much work remains to be done. To accomplish this important work, the discipline working groups will continue.

Finally it is evident from these reports that many individuals and groups have devoted appreciable effort to this important planning activity. I would like to express my appreciation for this effort and stress the importance of such activities if we are to realize the full potential of space systems in the 1980s.

John E. Naugle

John E. Naugle, Chairman
NASA Shuttle Payload Planning
Steering Group

LIST OF WORKING GROUPS

	GROUP NAME	CHAIRMAN	CO-CHAIRMAN
1.	ASTRONOMY	Dr. N. Roman (HQ)	Dr. D. S. Leckrone (GSFC)
2.	ATMOSPHERIC & SPACE PHYSICS	Dr. E. Schmerling (HQ)	Mr. W. Roberts (MSFC)
3.	HIGH ENERGY ASTROPHYSICS	Dr. A. Opp (HQ)	Dr. F. McDonald (GSFC)
4.	LIFE SCIENCES	Dr. R. Hessberg (HQ)	Dr. D. Winter (ARC)
5.	SOLAR PHYSICS	Dr. G. Oertel (HQ)	Mr. K. Frost (GSFC)
6.	COMMUNICATIONS & NAVIGATION	Mr. E. Ehrlich (HQ)	Mr. C. Quantock (MSFC)
7.	EARTH OBSERVATIONS	Dr. M. Tepper (HQ)	Dr. W. O. Davis (DoC/NOAA)
8.	EARTH AND OCEAN PHYSICS	Mr. B. Milwitzky (HQ)	Dr. F. Vonbun (GSFC)
9.	MATERIALS PROCESSING AND SPACE MANUFACTURING	Dr. J. Bredt (HQ)	Dr. B. Montgomery (MSFC)
10.	SPACE TECHNOLOGY	Mr. D. Novik (HQ)	Mr. R. Hook (LaRC)

ATTACHMENT A

NASA AD HOC ORGANIZATION FOR SHUTTLE PAYLOAD PLANNING

POLICY GROUP

H. Newell—Chairman
D. Myers
C. Mathews
J. Naugle
C. Berry
A. Frutkin

STEERING GROUP

J. Naugle — Chairman
R. Johnson — Exec. Secretary
L. Meredith
J. Mitchell
S. White
L. Jaffe
P. Culbertson
S. Himmel
H. Ortner (ESRO)

SCIENCE WORKING GROUPS

COORD./Mitchell

- ASTRONOMY/Roman
- SOLAR PHYSICS/Oertel
- HIGH-ENERGY ASTROPHYSICS/Opp
- ATMOSPHERIC & SPACE PHYSICS/Schmerling

APPLICATIONS WORKING GROUPS

COORD./Jaffe

- COMM. & NAV./Ehrlich
- EARTH & OCEAN PHYSICS/ Milwitzky
- EARTH OBSERVATIONS/ Tepper
- MATERIAL SCIENCE & SPACE PROCESSING/Bredt

LIFE SCIENCE WORKING GROUP

COORD./White

- LIFE SCIENCE/Hessberg

SPACE TECHNOLOGY WORKING GROUP

COORD./Hayes

- SPACE TECHNOLOGY/ Novik

ATTACHMENT B

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CONTENTS

CONTENTS (Continued)

ILLUSTRATIONS

ATMOSPHERIC AND SPACE PHYSICS

Working Group Members

Name	Affiliation
E. Schmerling, Chairman	NASA HQ
W. Roberts, Co-Chairman	MSFC
L. Kavanagh	NASA HQ
R. Hudson	MSC
A. Konradi	MSC
D. Adamson	LaRC
L. Brace	GSFC
S. Bowhill	Univ. of Illinois
N. Brice	Cornell University
T. N. Davis	Univ. of Alaska
R. Helliwell	Stanford University
W. Hess	NOAA
S. Krimigis	APL
F. Scarf	TRW/STL
D. Lind	MSC
R. Fellows	NASA HQ
C. Falthammar	Royal Institute, Sweden
K. Wilhelm	MPI - Germany
G. Haerendel	MPI - Germany

In addition, approximately 200 scientists from various locations around the world contributed experiment concepts in the discipline of plasma physics and environmental perturbations to Dr. Scarf; approximately 100 scientists contributed experiment concepts in the discipline of atmospheric science to Dr. Hudson; and approximately 70 scientists, in a two-day assembly in Houston, reviewed and constructively critiqued the magnetospheric and auroral physics concepts assembled by Drs. Konradi and Davis.

ATMOSPHERIC & SPACE PHYSICS WORKING GROUP

EXECUTIVE SUMMARY

OBJECTIVES

Three major objectives have been defined for the discipline in the Shuttle decade of the 1980's:

- Investigate the detailed mechanisms which control the near-space environment of the earth.
- Perform plasma physics investigations not feasible in ground-based laboratories.
- Conduct investigations which are important in understanding planetary and cometary phenomena.

In defining these objectives it has been assumed that the ongoing Explorer series of spacecraft — including the IMPs, the IME, the Atmosphere Explorers, and their follow-ons, especially the Electrodynamic Explorers — will have accomplished by 1980 the major task of surveying and cataloguing all the gross features of the near-earth interplanetary medium, the magnetosphere, and the upper atmosphere. Thus, the task for the 1980's will be to understand the dynamical processes of the sun-earth system, and to explore the cause-and-effect relationships. Most of this work can be best accomplished by short-term, definitive, active experiments which are ideally suited to the 7-30 day Shuttle Sortie mode of operation.

EXPERIMENT CONCEPTS

The major experiments which have been envisioned thus far for the 1980's all involve the Shuttle. These are:

ACTIVE EXPERIMENT — SHUTTLE AS OBSERVING PLATFORM

The release of a tracer (e.g. lithium) outside the magnetosphere, and the use of a Shuttle with diagnostic instruments can resolve rather directly the question of what fraction of the solar wind enters the forward magnetosphere near the neutral points, and what fraction enters through the tail.

ACTIVE EXPERIMENT — SHUTTLE AS SOURCE

The Shuttle can paint a significant fraction of an entire orbit with a chemical such as barium. Observing this trail — using aircraft and ground-based cameras — could provide more information on global circulation than many years of sounding rocket releases.

The use of an electron accelerator to generate an artificial aurora — to be observed on the ground or from aircraft — could provide definitive answers to the acceleration mechanism and plasma instabilities.

The stimulation of plasma resonances — to be observed from a sub-satellite — can provide immediate answers to basic questions of interaction volumes and resonant Fourier structure.

SHUTTLE AS PLASMA LABORATORY

The maximum power which can be pumped into an antenna before the process becomes self-limiting due to non-linear effects can be readily investigated in a number of plasma and radio-frequency regimes which cannot be modelled in a plasma chamber on the ground.

SHUTTLE AS PERTURBATION

The electromagnetic wake behind a Shuttle can be mapped with a maneuverable sub-satellite. Both the real wake (including out-gassing) and the pure electromagnetic wake from a clean test body can be mapped in detail.

SHUTTLE AS AN ATMOSPHERIC SCIENCE FACILITY

Gaseous reactions and excited states can be investigated by releasing kilograms of gas. These can be excited by the Sun, by laser beams, or by electron beams, and the reactions observed by instruments on the Shuttle or a sub-satellite.

SHUTTLE FOR WAVE-PARTICLE INTERACTIONS

To investigate wave/particle interactions using particles and waves generated on board, with those generated from the ground or found in-situ. These range from weak interactions to those strong enough to produce large perturbations in the radiation belts.

SHUTTLE AS A CIRCUIT-BREAKER

By releasing electron acceptors (such as sulfur hexafluoride) over the electrojet, it is possible to reduce conductivities sufficiently to stop the equatorial or auroral electrojet for times of the order of minutes. This will enable basic questions of electrodynamics to be investigated. Ground-based and rocket diagnostics will be needed.

SHUTTLE AS A PRECIPITATOR

The addition of small amounts of cold plasma at certain locations in the magnetosphere can produce rapid growth of wave instabilities and subsequent dumping of large amounts of trapped particles into the atmosphere. Shuttle experiments designed to release such plasma can point the way toward active control of the radiation content in the Van Allen belts.

LABORATORY CONFIGURATIONS

Prior to the formation of the Atmospheric and Space Physics Working Group, three separate studies had been initiated along traditional discipline lines to explore the needs of the various segments of the scientific community relative to the Shuttle. These resulted in separate requirements for three distinct Shuttle laboratories:

- A Plasma Physics and Environmental Perturbation Laboratory (PPEPL)
- An Atmospheric Science Facility (ASF)
- A Magnetosphere and Auroral Manned Observatory System (MAMOS).

This report thus represents a distillation of the ideas provided by about 300 contributors. When the Working Group came into being in late 1972, it was realized that the three facilities could profitably be combined into one module. A great economy of instrumentation could be obtained by recognizing, for example, that the electron gun on the PPEPL could provide an electron excitation source for ASF and MAMOS; that the concept of gas release cylinders on PPEPL could be used in conjunction with a laser to greatly enhance the study of atmospheric reactions on ASF; and that the sub-satellite required for the MAMOS key mission was similar in many respects to the subsatellite required for PPEPL.

The Working Group concluded that nine basic pieces of core instrumentation would form the building blocks for Sortie laboratories. Arranged in various configurations on the Sortie pallets, these would be used interchangeably on missions optimized for Magnetosphere, Atmosphere, or Plasma Physics Studies. A key finding is that the use of a small number of core instruments, flown repeatedly to perform many different experiments, results in a low-cost, economical approach to performing the needed research.

FLIGHT SCHEDULES

In order to perform most of the experiments which have been suggested thus far in these laboratory configurations, a flight program on the order of four Sortie flights per year over the decade of the 1980's is required, if each flight is assumed to be seven days in duration and two crew members are available to perform experiments. Thus, one or two dedicated Sortie laboratory shells will be required, and two pallets for instrument mounting. This would permit a six-month turn-around time for refurbishment of each laboratory between launches. It is felt that such a program, together with the ongoing Explorer series, should be able to answer most of the key scientific questions for the discipline in the 1980's, and that this approach achieves real economies by reflying the same group of instruments many times with only minor changes.

REPORT OF THE ATMOSPHERIC AND SPACE PHYSICS WORKING GROUP

INTRODUCTION

OBJECTIVES AND PURPOSE

The Space Shuttle brings with it both an opportunity and a challenge for the disciplines of Atmospheric and Space Physics. The opportunity is to perform the research needed to understand the phenomena discovered in the earth's near-space environment during the previous two decades. The challenge is to accomplish this by fresh, innovative, and low-cost methods of operation which make the best use of the new capabilities introduced by the Shuttle.

By the time the Shuttle becomes operational, the Working Group expects that the exploratory and survey phases of research in the earth's near-space environment will have been essentially accomplished. That is to say, we expect to have a fairly extensive catalog of the phenomena to be found in near-Earth space, and a rather good statistical knowledge of the variations in these phenomena to be expected with changes in season, latitude, solar activity, etc. Still to be accomplished, however, will be the more difficult task of achieving a genuine understanding of these phenomena, and an intimate knowledge of the cause-and-effect relationships which govern them. The lack of such knowledge is being felt right now in our inability to assess the long-range effects on man of modern technological developments such as supersonic transports and in our inability to determine the hazards to man of the particular types of pollutants already in our environment. Such ignorance is not merely of academic concern; it may have profound effects on the health and even survival of succeeding generations.

An enormously fruitful area for the Shuttle will be the use of space as a plasma laboratory, where experiments can be performed in a region essentially free from the wall-effects which so often bedevil the researcher in the laboratory on the ground. Also, using space as an atmospheric laboratory to perform experiments which have a bearing on cometary and planetary phenomena, the Shuttle will be an extremely useful tool to investigate the mechanisms which govern the environments of other bodies in the universe.

In summary, the three principal objectives of Atmospheric and Space Physics are as follows:

- To investigate the detailed mechanisms which control the near-space environment of the earth.

- To perform plasma physics investigations not feasible in ground-based laboratories

- To conduct investigations which are important in understanding planetary and cometary phenomena.

This study is concerned primarily with the Sortie mode, which has three important characteristics: it provides a high payload weight and size capability, a 7 to 21 day duration, and it allows the presence of man. These features can be used very effectively for all the major research needs foreseeable in the discipline, except for those which may require long-term data gathering. The high weight capability, in particular, is especially suited to the active experiments which use particle accelerators, high-power radio transmitters, lasers, and gas cylinders. Coupled with the 7 to 21 day duration, this capability should result in large reductions in cost due to the avoidance of tight-packaging and long-life design. The short duration then turns out to be a positive advantage, since properly designed definitive studies, which would never have been cost-effective in programs where typical lifetimes are three years, can now be considered as candidates for flight.

It would, of course, be presumptuous to suppose that there will be no surprises in store for us during the Shuttle era, or that there will be absolutely no requirement for further data of the long-term-survey type. We believe, however, that the main thrust will be as previously described, and that the ability to react to surprises and the necessity for filling in some gaps in our data banks can be taken in stride.

It would be even more short-sighted to suppose that the needs of Atmospheric and Space Physics can be met solely by packages mounted on a Shuttle. Indeed, we believe that the Shuttle is a vital element in an Atmospheric and Space Physics program, but not the sole element. For a great many novel and exciting experiments, other elements are needed. For example, if the entry of interplanetary particles is to be investigated as a crucial test of an auroral theory, test particles can be introduced at great altitudes from another vehicle, and the Shuttle used as a global observing-diagnostic platform. The vehicle which releases the particles outside the magnetosphere could be launched from the Shuttle or launched separately. If attempts are made to trigger a sub-storm from the Shuttle, ground-based observing stations will be needed. Many of these already exist. If global circulation patterns are to be investigated by releasing chemicals from the Shuttle over a complete orbit, then aircraft will be needed to observe the trails. If an artificial aurora is produced, some combination of other satellites plus ground stations and aircraft might be most appropriate to observe the effects. These are just a few examples, but they serve to illustrate the use of the Shuttle as a component in a research program which makes good use of the high-weight capability and 7 to 21 day features.

The succeeding sections of this report provide the following information:

- A survey of the current state of knowledge in Atmosphere and Space Physics
- Some important questions which need to be answered before presently known features can be fully understood
- Proposals for the use of the Space Shuttle to answer these questions.

MILESTONE DATES IN THE PREPARATION OF THIS DOCUMENT

1. Conference at Johnson Space Center (then Manned Spacecraft Center), September 1970, on use of a National Space Facility for Atmospheric Studies.

2. Conference at the Lunar Science Institute, May 1972, sponsored by JSC and the University of Houston, on Plasma Physics in Space with the Shuttle.

3. Workshop at Goddard Space Flight Center, July-August 1972, on the Shuttle in the Sortie mode of operation. Atmospheric and Space Physics Working Group formed at this conference.

4. University of Alaska preliminary design study on a Shuttle Auroral Science Facility. Results of conceptual design study presented, September 1972, at JSC.

5. Martin-Marietta Corporation preliminary design study on Shuttle Sortie Atmospheric Science Facility. Final report given, October 1972, at JSC.

6. Second meeting of Atmospheric and Space Physics Working Group, October 1972, at GSFC.

7. TRW Corporation preliminary design study on a Plasma Physics and Environmental Perturbation Laboratory. Final report given, February 1973, at MSFC and at NASA Headquarters.

8. Third meeting of Atmospheric and Space Physics Working Group, March 1973, at MSFC.

SCIENTIFIC DISCUSSION

MAGNETOSPHERIC AND AURORAL DYNAMICS

Background

Between 1958 and the present, a large community of space scientists from many countries have participated in an intensive and successful research effort to study the earth's magnetosphere. This program has been based almost entirely on use of passive large-scale observing techniques associated with analysis of data from ground-based facilities and from automated rocket and spacecraft payloads. Space scientists now have a good understanding of the overall configuration of the magnetosphere and the ionosphere and first-order information on the energetics of this system. The earth's space environment has been fairly well explored, in the sense that descriptions are available of many important parameters and boundaries. It has also been fairly well surveyed, in the sense that data are available on how these parameters vary in a general way with space and time. The major dynamical phenomena that occur in nature have been classified, and there is general knowledge of where and when the important events take place. Scientists are now ready for a new and very important stage of research, in which the objective is to understand the detailed mechanisms which result in the observed features and the physical interactions which bring them about. When these interactions are understood in sufficient detail, we will be able to explore the extent to which man can exert control over the space environment of the earth.

The program needed to complete our detailed understanding of the magnetosphere falls naturally into two phases. First, key information on some of the natural processes must still be obtained. This requires a modest but carefully designed and highly coordinated series of unmanned spacecraft launches, supplemented by ground-based, balloon- and rocket-observing programs. To this end, NASA has planned a magnetospheric spacecraft program for the remainder of this decade, with emphasis on operation during the International Magnetospheric Study (IMS), an international cooperative enterprise, to be conducted in 1976-1978. The Committee on Solar Terrestrial Research and the Space Science Board of the National Academy of Sciences recently appointed a panel to evaluate the IMS program, and the panel report strongly endorses participation by the United States, participation based on unmanned spacecraft missions currently approved (most notably the Mother/Daughter and Heliocentric missions) or under consideration. The coordinated IMS missions should answer many of the present significant questions concerning the large-scale dynamics and the general morphology of the magnetosphere. But since these missions acquire data primarily on uncontrolled natural processes, it appears certain that by the end of the 70's there will remain many important unanswered questions on the microscopic mechanisms that control the dynamics, as well as some gaps in our knowledge of electric fields and electrodynamic processes. The latter is the subject of an electrodynamics mission currently under study.

The second, definitive, phase of magnetospheric study will naturally involve a series of controlled or active experiments designed to give conclusive information on the detailed mechanisms that govern magnetospheric phenomena. These will not generally require long-term observations or the acquisition of large amounts of data. In subsequent sections of this report we show that the Space Shuttle Sortie missions provide an excellent platform for a wide variety of active experiments that can shed light on the important natural magnetospheric processes. These same Shuttle Sortie missions will also allow magnetospheric scientists to search for ways to perturb and control the earth's plasma environment.

In some ways, the history of research in solid state physics provides a parallel with this type of multiphase magnetospheric exploration program, a program that leads first to general knowledge, then to detailed understanding, and finally to the ability to exert control.

The earliest investigations of the solid state were primarily concerned with the massive energetic ions, and with general studies of structure and interatomic forces. At this time, the concept of the metallic state was treated in terms of a simplified two-fluid model, while detailed analysis of the individual electron states and their collective modes was deferred, largely because it was noted that the oscillations of the electrons contributed a negligible amount to the overall energy balance. However, when the band theory of electrons in solids was developed, it became obvious that these collective oscillations of electrons in a positive ion lattice played the dominant role in determining the macroscopic properties of the crystal. The study of the wavelike oscillations of the electron medium in the solid state plasma led directly to the fundamental understanding of the diverse mechanisms that govern the normal, semiconducting and superconducting metallic states, the phenomenon of ferromagnetism, and many other related large-scale crystalline properties. Once this detailed understanding was achieved, it became possible to control macroscopic characteristics of solids by irradiating the material, by deliberately seeding "contaminants" at specific lattice sites, and by modifying boundary conditions at surfaces and junctions. The active control program that gave birth to the transistor and many other new and useful solid state devices could not have developed without our first achieving a detailed understanding of waves and interactions in solid state plasma. Similarly, a program aimed at understanding and controlling the earth's space environment requires full analysis of the plasma physics mechanisms that govern the dynamic behavior and interaction of the magnetosphere and ionosphere.

In the remainder of this section we summarize the present state of understanding of the magnetosphere and discuss briefly the advances anticipated in this decade from the currently-approved or planned programs. This is followed by a discussion of the important scientific questions that can be answered conclusively only when controlled or active experiment programs can be conducted. It should be pointed out here that the design of many of these experiments requires the detailed descriptive knowledge of the earth's space environment which is now being acquired in the current program of space exploration.

Present Understanding of the Magnetosphere

The terrestrial magnetic field, generated by a dipole-like source deep within the core of the earth, is terminated on the sunward side of the earth at a location where an energy balance exists between the terrestrial field and the charged particles of the solar wind. This "stand-off distance" is typically at an altitude of approximately nine earth radii, and it varies with solar wind strength. Through a viscous-type interaction, the solar wind extends the terrestrial field into a long, comet-like tail in the anti-solar direction. The earth and its field are thus confined to a cavity — the magnetosphere — carved into the wind. The following discussion refers to features identified in Figure 1.

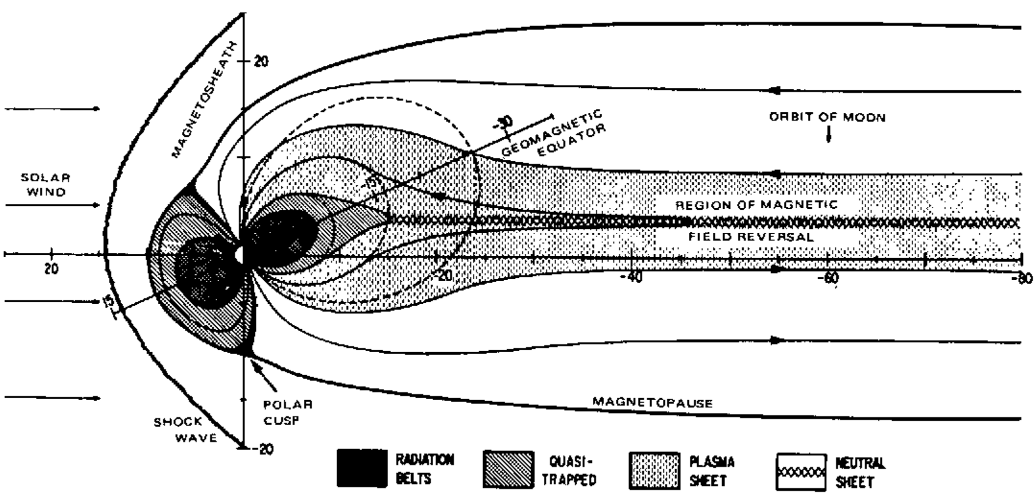


Figure 1. Magnetosphere

The magnetospheric surface consists of the magnetopause and the neutral sheet. The magnetopause includes the cusp region at high latitudes on the dayside. The cusp appears to separate field lines (originating from the earth's surface on the dayside) that close through the equatorial region on the dayside from those that extend into the geomagnetic tail. Over the past several years, a large number of observations have gradually contributed to the very significant and now generally accepted idea that there is interconnection between the interplanetary magnetic field (carried by the solar wind) and the terrestrial field. Although the location of the region of interconnection is presently unknown (and undoubtedly changes with time), the fact of interconnection has been most evident, perhaps, in the flow of solar-wind particles through the cusp region to form a portion of the high-latitude dayside auroral precipitation region.

The neutral sheet in the geomagnetic tail extends approximately across the entire tail, and it joins the magnetopause at the two flanks. The neutral sheet is imbedded in a current-carrying plasma sheet. The plasma sheet, responsible for much of the electrodynamics of the magnetotail, extends to an altitude of approximately seven earth radii on the night side during geomagnetically quiet times. The non-vanishing electrical resistivity of the plasma sheet and the viscous solar-wind interaction at the magnetopause probably produce the large-scale convection electric field across the magnetosphere and tail.

Within the magnetosphere, the rotation of the earth creates an electrostatic field whose equipotential surfaces form closed shells. These closed shells prevent the escape of cold magnetospheric plasma of ionospheric origin and thus form the plasmasphere, with a boundary called the plasmapause. The equatorial altitude of the plasmapause changes as the strength of the large-scale convection electric field varies with the amount of geomagnetic activity. The convection electric field also provides the mechanism for the transfer (via $\vec{E}x\vec{B}$ drift) and energization (via conservation of magnetic moment) of plasma sheet particles from the tail to the inner magnetosphere.

Radiation belt particles within the magnetosphere consist of those permanently trapped particles whose motions are defined entirely by the confining magnetic field. Radiation belt electrons (about 100 keV to several MeV in energy) are located predominantly in two toroids known as the inner zone and outer zone. Radiation belt protons are distributed throughout the magnetosphere, with the highest energy particles (hundreds of MeV) being dominant in the region of the inner electron belt and the lowest energy protons (few tens of keV) being dominant in the region of the outer zone. These lower energy protons (and electrons of similar energies) are the high-energy tail on the distribution of hot plasma particles in the magnetosphere. The motion of these hot plasma particles (with energies of a few hundred to a few thousand eV) is determined both by the terrestrial magnetic field and by the convection electric field.

The dayside cusp and nightside plasma sheet regions are thought to project along the geomagnetic field to form the auroral oval, the instantaneous locus of discrete auroras. Thus the auroral oval coincides approximately with the boundary of the area of solar wind ion bombardment and with the projection line of the outer boundary of the inner magnetosphere. The electric field direction reverses along the oval, and intense field-aligned currents flow into and out of the oval. In essence, the auroral oval marks the ionospheric termination of those magnetic field lines upon which a majority of the important magnetospheric processes take place. It is here that there probably occurs the greatest energy transfer from the magnetosphere to the ionosphere through particle precipitation and Joule heating. The auroral oval and the region connecting to it are highly structured, both spatially and temporally, and are subject to important instability processes; the oval itself changes location and configuration as a function of activity. The behavior of visual auroras and related phenomena within the oval are indicative of processes throughout much of the magnetosphere.

It is now common to view the magnetosphere either as being in a quiet state or as undergoing a substorm. The magnetospheric substorm involves a complex sequence of physical processes, and this term — substorm — describes what appears to be the most important dynamical variation in the magnetosphere. Radical changes in configuration of parts of the magnetosphere and in the rates of various processes occur during the substorm. Magnetic storms are recognized as being composed of substorms lasting one to three hours. During a major substorm, kinetic energy appears in the trapped particle populations at a rate near 10^{19} ergs/sec, and an equal amount of energy is precipitated into the auroral ionosphere. These rates are two orders of magnitude higher than the energy injection rates during quiet times.

Outstanding Problems of the 1970's

The space physics program planned for the remainder of this decade is based on a modest framework of highly relevant automated spacecraft missions designed specifically to answer certain key questions about the magnetosphere and the ionosphere. Before the IMS period, NASA has scheduled for launch an interplanetary and geomagnetic tail spacecraft (IMP-J), a satellite to explore the high latitude polar cusp (Hawkeye), and a comprehensive scientific package to investigate the plasma sheet characteristics at synchronous orbit (ATS-F). The polar orbiting Atmospheric Explorer (AE-D) will obtain global information on the ionosphere-magnetosphere coupling and energy balance.

The central core of the IMS program will involve the NASA/ESRO International Magnetosphere Explorers (Mother-Daughter-Heliocentric missions), the ESRO/GEOS satellite, and a coordinated ground-based, balloon- and rocket-observing program.

These spacecraft missions are designed to answer some of the outstanding global problems that now face space scientists. One of these questions concerns the sequence of events that take place during a magnetospheric substorm.

The substorm is one of the most pronounced examples of solar-terrestrial interaction; it is generally recognized that an understanding of this phenomenon is of critical importance for understanding magnetospheric structure and dynamics. During the substorm phenomenon, large amounts of energy (primarily in the form of hot plasma and enhanced electric fields) are injected into the inner magnetosphere, and in the process nearly every dynamical property of the magnetosphere is affected. The substorm is complex and it is now defined by the related phenomena which it produces and the time sequence in which these phenomena occur. A detailed discussion is conveniently built around a block diagram such as that shown in Figure 2. Substorm activity generally begins when the interplanetary magnetic field turns southward and remains so for a sufficient length of time. This is thought to initiate a process whereby an enhanced dawn-to-dusk electric field is established across the magnetotail. The enhanced electric field has the effect of enhancing convection, contracting the plasmasphere, enhancing the crosstail current, and thinning the north-south extent of the magnetotail

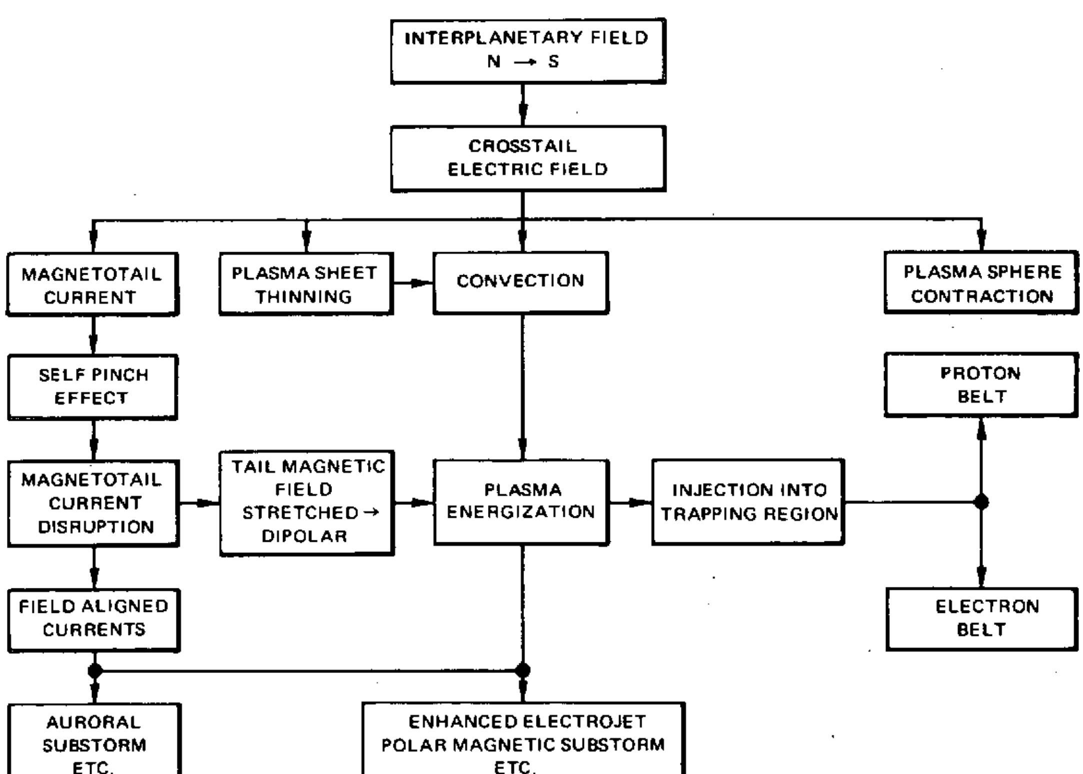


Figure 2. Magnetospheric Substorm, after S-I. Akasofu (modified slightly)

plasma sheet via $\vec{E} \times \vec{B}$ drift. The latter probably enhances convection, as shown in the diagram in Figure 2, by contributing to the injection of plasma into the magnetosphere.

The enhanced tail current is thought to produce some instability (possibly due to the pinch effect, as shown, but also possibly due to other instabilities) which disrupts this current. However, due to the large inductance and small resistance of the equivalent electric circuit, the current loop cannot suddenly cease to flow, but must be redirected by means of field aligned currents so as to close in the ionosphere through a westward electroject. The newly-formed current loop to the ionosphere has a certain inductance preventing a buildup of current as rapid as the one observed unless the loop has a small east-west extent initially. Thus it seems likely that the collapse of the tail field to a dipolar form should start within a limited region, the subsequent expansion perhaps corresponding in the ionosphere to the prevalent westward auroral surge. Overall, the complete restructuring of the electric fields and current circuits within the magnetosphere thought to occur during a substorm would seem to be sufficient to produce all the observed phenomena, although detailed verification is still lacking.

The Mother-Daughter-GEOS-Heliocentric spacecraft missions planned for operation during the IMS are designed to shed light on the general validity of the hypothetical sequence of events discussed above and in Figure 2. The Heliocentric spacecraft will measure the interplanetary field orientation; the Mother-Daughter combination will measure magnetotail current, plasma sheet thinning, and convection; and GEOS instrumentation will provide coordinated information on plasma energization and near-earth tail current changes. Ground-based observers will be able to measure additional auroral and electrojet effects. These coordinated observations should certainly answer many of today's pressing descriptive questions concerning the timing of dynamical changes during substorms and the identification of spatial locations for these changes. If these vital programs are successfully carried out, much progress should also be made on many other important large-scale questions concerning the solar-wind input to the magnetosphere, the nature of magnetospheric boundaries, the location of particle acceleration regions, and the energy budget in the magnetosphere and ionosphere. Since these programs will provide only very small samples in space and time of processes occurring over very large regions of space, it is hardly to be expected that these samples can be fitted to unambiguous interpretations. Thus, it is anticipated that by the end of this decade, space scientists will have completed the exploratory and survey phases of research in the magnetosphere. It is also anticipated that the scientific community will then be concerned with conducting controlled experiments in space to analyze the detailed mechanisms that govern the natural magnetospheric processes and to test rival hypotheses for explaining the phenomena previously observed.

Outstanding Magnetospheric Physics Problems of the 1980's

Any attempt to forecast the outstanding problems to be faced in a scientific discipline ten years from now is obviously dangerous, and in the young and rapidly progressing field of magnetospheric science there is much room for change in objectives and priorities. However, in the 1968 NAS/SSB report "Physics of the Earth in Space," the panel members were already able to state the following: "It is commonly recognized that one of the major obstacles in magnetospheric research is that phenomena of natural origin are largely unpredictable and certainly uncontrollable. Accordingly, efforts have been made in the past to induce controlled, or man-induced, effects in the magnetosphere. Such studies are a rational accessory to the study of natural phenomena " (p. 65).

This recognition of the need for active or controlled experiments has become more widespread in recent years as the exploratory and survey phases of magnetospheric research approach completion. At the joint COSPAR/IAGA/URSI Symposium "Critical Problems of Magnetospheric Physics" (Madrid, May 1972), an important paper, "Controlled Experiments in the Earth's Magnetosphere," was presented by Soviet scientists. The 1973 NAS report on the International Magnetospheric Study contains strong recommendations for a number of experiments in this area, and at the forthcoming IAGA Scientific Assembly (Kyoto, September 1973) there is presently scheduled a three-day Workshop on Controlled Magnetospheric Experiments that will include sixteen invited talks. We draw on these extensive background activities to predict some of the critical problems that cannot be solved unambiguously merely by using passive observing techniques.

Magnetosphere Configuration, Particle Trajectories, and Convection — Although the gross configuration of the magnetosphere is now established, basic questions will remain concerning the location of open and closed field lines, the relations between conjugate phenomena, and the convection or flow patterns in many regions of the magnetosphere. Local measurements can never give unambiguous information on large-scale dynamical effects, and multiple spacecraft systems such as Mother-Daughter will be able to distinguish between only the local space and time changes. In order to advance the understanding of the overall magnetosphere configuration, it appears necessary to rely on large-scale tracing techniques. Much developmental activity is presently underway in this area.

Similar problems arise when we consider questions concerning the origin of the observed particle or plasma distribution in the magnetosphere. Energetic particles may diffuse and convect in from the solar-wind, or they may originate in the ionosphere and flow out as a polar-wind. In addition, some of the less abundant particle species ($Z \geqslant 2$) at higher energies ($E \geqslant 0.2$ MeV/nucleon) may be directly captured into trapped orbits after being accelerated at the sun during solar flare events. The actual sources can be definitively inferred only by carrying out experiments using injection of tracer elements whose relative abundances and charge states are different from those in the solar-wind and ionosphere. Particle echo experiments conducted from orbiting spacecraft will give valuable supplementary information on loss and precipitation phenomena.

Tracer experiments of various kinds can also give unique and definitive information on the convection of charged particles in the high latitude auroral regions and on the thermal plasma flow characteristics in the polar-wind and plasmasphere boundary regions. These plasma tracer investigations can also be thought of as experiments designed to measure global electric field patterns, including distributions and characteristics of parallel electric fields, free from the small-scale fluctuations which make it very difficult to interpret direct-measurement sensors.

Some of the outstanding questions in these areas are as follows:

1. Does the low-altitude locus of open- and closed-field lines form a simple surface that intersects the auroral oval in the ionosphere, and how does this oval vary with time and magnetic activity? Can tracer techniques be developed to identify and study this boundary between open- and closed-field lines?

2. Where do the various magnetospheric particle populations (radiation belts, plasma sheet, ring current, auroral particles) come from? Can specific tracers released into the solar-wind or deep in the magnetosphere be detected in low earth orbit or on Shuttle-launched sub-satellites, and can these studies be used to provide conclusive answers on particle sources?

3. Do particles with different (Z/A) values experience the same acceleration and loss mechanisms? Can one use tracers with different (Z/A) values to answer these questions?

4. What are the loss mechanisms for radiation belt particles, and can orbiting electron-echo type experiments be developed to provide global answers for varying magnetospheric activity conditions?

5. What are the distributions of parallel electric fields (i.e., how does E vary with magnetic latitude, time, position along field line), and how are these fields related to the varying and non-uniform current systems in the magnetosphere and ionosphere? Can new active experimental

techniques (perhaps involving reflection of charged particle beams from an accelerator or beam transmission from the Shuttle to a field-aligned sub-satellite) be developed to give non-local information on parallel electric fields?

6. How do the convection patterns depend on ionospheric conductivity during quiet times and during substorms or auroral precipitation events? Can one artificially modify the ionospheric conductivity (by heating the ionosphere via a parametric instability, by injecting a specific release, by modifying the precipitation flux) in order to evaluate the mechanism and its importance under controlled conditions?

7. What are the flow characteristics of the polar-wind and where does the polar-wind end? Can this entire process be investigated by releasing a sizeable amount of Helium in the topside ionosphere, with subsequent observation and tracking of the Helium resonance line?

8. What are the density profiles and convection properties of the very low density cool plasma beyond the plasmapause? Can forward radar scatter techniques (ground-to-spacecraft or spacecraft-to-spacecraft) be developed to shed light on this problem?

Wave-Particle Interactions, Particle Acceleration, and Scattering — The magnetosphere is populated by low-density plasma distributions from several sources. As noted, cool plasma flows outward from the ionosphere, and much higher energy particles convect toward Earth from the tail, enter by way of the dayside polar cusps, or diffuse inward from the magnetopause. Instabilities driven by plasma non-uniformities or anistropic velocity distributions can generate electromagnetic and electrostatic waves while individual particle motions can be strongly affected by the wave fields. Such wave-particle interactions are responsible for the non-adiabatic magnetospheric processes of radial diffusion transport, pitch angle scattering, and local plasma acceleration, and are central to the dynamics of such large-scale phenomena as substorms and aurorae. Although resonant interactions between energetic trapped particles and various wave modes are thought to determine the structure and stability of the radiation belts, few of the important proposed wave-particle interactive processes have been experimentally confirmed and studied in detail. Waves can be generated on the Shuttle Sortie Laboratory, and wave and particle measurements on remote platforms (booms or associated sub-satellites) can give instability scale sizes, characteristic growth times and propagation velocities. Similar measurements made in conjunction with active experiments involving the emission of powerful electromagnetic waves, or the injection of cold plasma in regions beyond the plasmapause, with correlated ground observations of precipitated particles and waves, would provide exceedingly important data, data verifying definite wave-particle interactions under controlled conditions.

Related problems arise when we ask about the mechanisms for generation of natural magnetospheric wave modes such as chorus, high frequency electrostatic emissions, VLF and ELF hiss, and triggered emissions. These modes are thought to be generated by plasma instabilities from specific particle distribution functions, or to be radiated from some quasi-coherent processes. Parametric instabilities and wave-wave interactions may play important roles. In order to understand the various mechanisms for wave generation, the investigator must control the local plasma distributions to some extent, and he must have flexible wave generating equipment at his disposal.

Current-driven plasma instabilities are also thought to be related to the development of parallel electric fields as the currents radiate electrostatic waves that scatter particles and produce anomalous resistivity. The anomalous resistivity produces limiting of the current flow and energy transfer to the particles; the effect is expected to operate in auroral arc regions as well as at the bow shock and at magnetic field neutral lines or surfaces.

Some important questions in these areas are:

1. Do electromagnetic whistler mode waves in space cause sufficient pitch-angle scattering of charged particles to account for observed precipitation events and limiting of stably trapped fluxes? Can controlled experiments to examine the cyclotron resonance interaction mechanism be carried out using transmitters and antenna systems orbiting within the ionospheric or magnetospheric plasma? Can sufficiently large-amplitude low-frequency waves be generated in space? How do these transmissions distort the sheath and plasma around the spacecraft?

2. What determines the transmission and reflection properties of the ionosphere for low-frequency electromagnetic waves? Under what conditions can large-amplitude waves generated in the space plasma be made to propagate to the earth?

3. What wave-particle interaction mechanisms are responsible for the spontaneous generation in the magnetosphere of chorus, pearls, and triggered emissions? Can experiments with phased arrays of electron-ion accelerators orbiting within the ionospheric or magnetospheric plasma be conducted to provide answers to these questions?

4. How efficient are electrostatic wave modes as sources for particle energization and pitch angle scattering?

5. Are the various wave-particle interactions that occur in the magnetosphere most suitably discussed in terms of linear, quasi-linear, or completely non-linear descriptions?

6. What roles do parametric plasma instabilities play in nature? Can experiments in the unbounded space plasma be designed to investigate natural wave-wave interaction mechanisms that may couple long wavelength electromagnetic modes to short wavelength electrostatic oscillations?

7. What are the effective transport coefficients associated with wave-particle interactions in the magnetosphere and ionosphere? Can experiments be carried out to evaluate the effective coefficients of resistivity, viscosity, heat conductivity as functions of the ambient parameters for quasi-linear and non-linear situations?

Large-Scale Dynamical Processes in the Magnetosphere — Many of the striking and important dynamical phenomena that occur in nature, such as those involved in substorms and auroras, can never be fully understood on the basis of uncontrolled passive observations alone. For instance, the variability and motion of a natural auroral arc might be explained in terms of changing large-scale electric fields that lead to rapid motions of the suprathermal particle beams that cause the optical displays. However, the observed auroral "flickering" may also be explained in part by changing coherence effects in the beam. When the beam size, density, and streaming energy are appropriate, the auroral beam could dissipate much of its energy by collective interactions in the region above the normal visible aurora. In this case the particles that bombard the ionosphere may be regarded as locally-accelerated secondaries, rather than the primary auroral particles.

Similar complex questions arise when we consider the effects of ionospheric conductivity on the observed arc structures and motion, since beam-induced plasma turbulence can provide an anomalous enhanced resistivity that may modify the voltage drops along the primary beam trajectories.

In summary, the large-scale dynamical processes that actually occur when substorms, aurora, SAR red-arc, and ring current decay events take place are so complex and inherently non-linear that true understanding of the basic mechanisms will not be achieved unless an orderly program involving controlled experiments is conducted. Some of the main questions to be answered are the following:

1. Can the aurora be "calibrated" under controlled conditions so that subsequent auroral observers will be able to deduce the origin and characteristics of the primary particles?

2. To what extent is an auroral beam correctly described in terms of individual particle effects? Where and when are collective interactions important? Can one make suprathermal particle beams of sufficient density, streaming energy, and beam size to generate two-stream instabilities so that beam-induced turbulence and collisionless dissipation and acceleration mechanisms can be studied in space?

3. Over what regions of space can artificial auroras and midlatitude (SAR) arcs be generated, and to what extent can insight into the natural generation mechanisms be obtained by studying the beam-induced emissions?

4. What are the non-linear response characteristics of the ionosphere to controlled fluxes of suprathermal particles? How is the stream neutralized and where do return currents come from?

5. To what extent can the ionosphere be modified by RF heating, stimulation of parametric instabilities, or other means? Can the ionospheric conductivity or wave reflection and transmission properties be modified by these techniques? Can the magnetosphere-ionosphere coupling be modified, and if so, how does this modification affect natural substorms and auroras?

6. What mechanisms provide limiting of the stably-trapped proton and electron distributions? Can the natural radiation belt population be enhanced by injecting fresh particles into trapped orbits? Can the belts be depleted by artificial injection of plasma waves or by artificial modification of ambient parameters so that growth rates for natural plasma instabilities are changed? Can the radiation hazard be controlled so that the range of orbits for manned spacecraft operations is less restricted?

7. Does a single mechanism trigger the explosive phase of each substorm? Can substorms be triggered artificially? Can the instabilities be quenched?

AERONOMY

Background

Aeronomy deals with the "Inner Magnetosphere," from the lowest heights where ionized particles and ion reactions are of significance, to the plasmapause, which marks the boundary between ionospheric (cold) plasma of essentially terrestrial origin and hot plasma of (presumably) solar origin. This region in space is characterized by the absorption of solar photons, which produces the ionospheric plasma, and by a variety of dynamical and chemical processes which modify and distribute it. The discipline of aeronomy is, therefore, concerned with the neutral atmosphere, with the solar photons and particles which interact with it, with the neutral and ionized products of this interaction, with their distribution, and with the processes which control their distribution.

Much progress has been made in exploring and surveying the region above 250 km. An important gap exists in the 125-250 km region, where most of the solar photons are absorbed. This region has not yet been systematically investigated, but it is planned to do this with the Atmosphere Explorer AE/C, D, E spacecraft, which will be equipped to measure simultaneously the neutral constituents, the incident photon flux and the ionized constituents. A possible mission to investigate the electric fields and large-scale dynamics has also been considered, but no firm plans for an Electrodynamic Explorer have yet been approved.

A great deal of descriptive information is available about the atmosphere and the ionosphere, and some understanding has been achieved concerning their gross features. It is still possible, however, to ask some elementary questions which have no clear answer. These are:

1. Why are there twice as many electrons in winter as in summer for typical mid-latitude ionospheres at periods of moderate solar activity?

2. How is the ionosphere maintained during the long polar night?

The detailed geographical distributions of both the ionized and neutral constituents contain many "anomalies" which, it is fair to say, are not understood. We suspect that they result from large-scale dynamic effects, but no good theory is available. Similar remarks can be made concerning the temporal fluctuations of the temperatures and concentrations at fixed locations. Here more work is also needed on energy flow, as well as on the coupling with regions above and below those of interest.

Thermosphere Dynamics and Thermal Structure

The behavior of the thermosphere, the region of our atmosphere between perhaps 100 and 400 kilometers, is vastly more complex than had been anticipated before the advent of satellites. Recent satellites such as OGO-6 and ISIS-II have begun to reveal some of this complexity and are able to correlate the behavior of many atmospheric parameters. However these satellites, and others now planned, are not designed to provide the full range of measurements needed to resolve the dynamic behavior of this region.

Investigations of the thermosphere have thus far been largely confined to measuring scalar quantities such as temperatures and compositions of the ionized and neutral components. Vector quantities — e.g., temperature gradients, winds, ion fluxes and electric fields — which define to a great extent the dynamic properties of the thermosphere, have had to be inferred indirectly from scalars with the aid of theoretical models. Due to the limited altitude range of observations, initial values and boundary conditions are not sufficiently well determined for these models (no matter how thoroughly developed); hence any theoretical inference of vector quantities cannot be unique. Measurements of vector quantities would thus constitute a major step forward toward an understanding of the thermosphere dynamics and its interaction with the magnetosphere and the lower atmosphere. The Shuttle provides an ideal platform for measuring winds and flows in the atmosphere, both by in situ sensors and by chemical releases. The Shuttle makes it possible to use sufficient chemical tracers to observe the wind pattern over a major portion of an orbit, thus revealing more about global circulation in one day than can be achieved by years of work using sounding rockets.

The thermospheric response during magnetic storms has shown the energy deposition by particle precipitation (Joule heating and ion drag) comparable to the solar EUV heat input. OGO-6 composition measurements furthermore suggest that the semi-annual variation of thermosphere density is to some extent related to the semi-annual effect in the occurrence of magnetic storms. The importance of magnetospheric processes for the ionosphere is well established. Many of the questions of the dynamics of the thermosphere are related to interactions with regions above and below. For example:

1. What is the relative importance of Joule heating at thermospheric heights and particle energy deposition in the mesosphere for causing the magnetic storm response of the thermosphere?

2. How significant are electric field-induced ion drifts at F_2 region heights for the global circulation in general, and are electric fields more important during disturbed conditions than during undisturbed conditions?

How far down into the atmosphere do the effects of momentum transfer between the ionosphere and the neutral atmosphere extend?

3. What is the relative significance of electric fields generated in the magnetosphere and in the dynamo region of the thermosphere under various conditions?

4. Are hydromagnetic waves a significant heat source for the thermosphere?

5. What is the relative importance of electric fields and thermospheric winds for the global distribution of the ionosphere, and how significant are both during storms?

6. Can the apparent super-rotation of the thermosphere be verified by direct measurements? What is its height distribution? Are its generation mechanisms related to electric fields or to hydrodynamic processes?

7. What are the flow characteristics of the polar-wind for H^+, He^+, and O^+ ion concentrations in the thermosphere and how much does the polar-wind escape mechanism affect the He and H budgets of the Earth?

8. Do the electric fields induced by the solar-wind produce the plasmapause, and how does the resulting plasma convection modify the polar-wind?

Energy Deposition by Superthermal Electrons — Quantitative experiments to examine the deposition of particle energy in the thermosphere require a controlled stimulus and direct measurements of the response of the thermosphere, preferably measurements performed at moderate distances from the source. The combination of the Shuttle as a platform for the test particle injection and a suitably instrumented subsatellite to measure the thermosphere response would appear to be an effective tool. The following questions could be answered by such active experiments:

1. What are the thermal effects of an electron beam in the atmosphere?

2. What is the efficiency for airglow excitation? This is especially needed to establish the utility of airglow observations as remote indicators of the state of the atmosphere?

3. How are the energy and pitch-angle distribution of the incident beam of particles modified by the beam's encounter with the ambient thermospheric particles?

Non-equilibrium Plasmas — There is evidence that thermospheric ambient electrons may exhibit departures from a Maxwellian velocity distribution. Since various types of devices used for temperature measurements are affected differently by non-Maxwellian plasmas, it is possible to detect such conditions by *in situ* comparisons of a variety of such devices. Measurements based on radio propagation reflect the low-energy portion of the energy distribution, while direct probes and traps measure the higher energy portion. These devices, carried on a Shuttle, could identify regions of non-equilibrium plasma and, with the aid of other measurements, could determine their source.

Thermosphere Chemistry

Chemical Processes in the Thermosphere — Because the concentrations of atmospheric constituents diminish rapidly with altitude, the time constants for chemical reactions between the neutral and ionized constituents increase correspondingly. At altitudes above about 150 km, the time constants of most of the significant chemical processes for the neutral atmosphere are longer than that for vertical molecular diffusion. Therefore, the concentrations of most neutral constituents in the upper thermosphere are determined by their chemistry at altitudes between about 90 and 120 km, which has come to be described as the "lower boundary" for chemical problems of the neutral thermosphere (see "Outstanding Problems of the 1970's" p. 8 above). For the ionized constituents, the lower boundary is at the peak of the F2 layer, at about 250 km altitude. Above their lower boundary regions the neutral and ionized parts of the thermosphere are dominated by dynamical processes of the kind described in detail in the previous section. However, these processes have significant chemical aspects, which are described below.

Chemical Consequences of Thermosphere Dynamics — Changes in chemical composition at the lower boundary of the thermosphere combine with changes in its thermal structure to produce horizontal gradients in thermosphere density and composition. The horizontal flow that results from these gradients has four principal effects, as follows:

- Production of diurnal and seasonal changes in thermosphere composition
- Vertical flow at certain altitudes with chemical and energetic consequences at the lower boundary
- Neutral-composition effects on the ion chemistry and therefore on the electron concentration

- Distortion of the ionization profile to produce the hightime upper E-region valley and height changes in the F layer.

Some questions arising from these effects are listed below:

1. How is the composition of the thermosphere affected by changes in eddy diffusion at the lower boundary, and by horizontal flow in the upper thermosphere?

2. Is the shape of the F layer below its peak primarily a result of height-changing chemical processes, of electric field effects, or of forces exerted on the ionization by the neutral flow?

3. Are seasonal and annual effects in the F layer, such as the winter anomaly, explicable in terms of corresponding changes in the neutral composition, or in terms of flow into the F layer from the topside; or are both effects involved?

4. What role do chemistry and dynamics play in the maintenance of the F layer during the polar night?

Excited Neutral and Ion Species—Another important problem concerns the distribution of energy in the vibrational modes of the molecular, neutral, and ionized ambient particles. The distribution of energy in the vibrational modes of these species can have extremely important effects on the chemical reactions involving these ionized and neutral species. The case of N_2 is particularly illustrative and interesting because this molecule is inactive optically in the infrared (as is O_2) and the translational vibrational energy coupling is weak (whereas in O_2 it is strong). The N_2 molecule plays an important role in the ionosphere through the reaction $O^+ + N_2 = NO^+ + N$, which is the rate-determining reaction for loss of F_2 region ionization. The rate coefficient for this reaction is strongly dependent upon the vibrational temperature of N_2. Thus, the vibrational temperature of N_2 is important not only for normal ionospheric conditions, but also under disturbed conditions. Indeed, where Te is large, it may be most important. The N_2 molecule lends itself to measurements which yield the vibrational temperature. The application of laboratory techniques to in situ aeronomy measurements appears to be feasible and is under investigation.

These techniques may also be appropriate to other molecular neutral and ionized species. If the feasibility study is positive, then this may be an important new measurement, utilizing existing technology, appropriate for the Shuttle. Electronic excitation of neutral and ion species is also important, as many of the photons absorbed in the F region have sufficient excess energy to excite numerous electronic states.

Significant questions include the following:

1. What are the processes which determine the vibrational temperature of molecular constituents in the thermosphere, and how are they related to changes in electron temperature under quiet and disturbed conditions?

2. What laboratory techniques for measurements of excited species concentrations can be adapted to thermosphere measurements?

3 How is the ionization distribution in the F region affected by changes in ion-molecule reaction rates produced by changes in vibrational excitation of the reacting species?

Chemical Rate Constants in the Upper Thermosphere—Even in the part of the F layer below its peak, where transport processes may usually be neglected, agreement between measured and calculated electron densities is not satisfactory. Ion production rates can be calculated from measured EUV solar fluxes and the known densities of the major neutral species. Electron loss rates can be calculated from laboratory measurements of ion-molecule reactions and known concentration of molecular species. And, if the ion chemistry is known, electron concentrations can also be calculated. Improved accuracy in the determination of these quantities has not yielded satisfactory agreement: the electron loss rates from laboratory measurements generally appear to be a factor of from two to four too large to explain the observed ion densities. Significant processes are probably being neglected, even in the quiet-time ionosphere. The following questions arise:

1. Are the ionization and absorption cross sections used in the ion production calculations applicable to the line spectrum observed in the solar EUV?

2. Are the absolute values of photon fluxes for EUV spectral lines measured with adequate accuracy?

3. Do the energy states of the reactants and reaction products in laboratory measurements of ion-chemical reactions in the F layer correspond to those in the ionosphere?

4. What is the effect of a non-Boltzmann distribution of electron or ion energies on the ionization equilibrium?

Optical Emissions in the Upper Atmosphere—Observations of the red (6300A) and green (5577A) emissions of atomic oxygen in the F layer show strong variabilities in all parts of the globe. Even the simple recombination emission from the midlatitude F layer is not wholly understood. In addition, it has been suggested that changes in chemical composition of the thermosphere may be a necessary condition for the production of SAR-arcs. There is little doubt that the capabilities of the Shuttle to carry optical sensors of much higher angular and spectral resolution will lead to the identification of new species of excited particles and to much better determination of the distribution of minor constituents generally. The capability of the Shuttle to carry its own source of excitation (high-intensity lamps, an electron accelerator, lasers) promises to add a new dimension to our ability to investigate excitation mechanisms and reaction rates. The following are just a few of the scientific questions which existing and planned programs will not be able to resolve:

1. What are the causes of spatial and temporal variabilities in thermospheric optical emissions?

2. How does the development of SAR-arcs correlate with other variables such as composition, electric field and thermal structure?

3. How many of the major and minor constituents of the thermosphere and ionosphere can be mapped in their vertical and horizontal dimensions by resonance-line emission?

Coupling Between Lower Atmosphere and Thermosphere

The problems in understanding the coupling between the lower atmosphere and the thermosphere are related to the following questions:

1. What are the propagation characteristics of the diurnal and semi-diurnal tides in the transition region between the mesosphere and thermosphere where the wind field changes from a near geostrophic pattern((influenced by eddy viscosity and Coriolis force) to an ageostrophic pattern (influenced by molecular viscosity, ion drag and electric fields)? This region includes the dynamo region between 90 and 125 km which is significant for magnetic field effects.

2. What are the turbulent transport properties of the mesosphere and how do they affect the wind field, the composition and the energy budget of the atmosphere?

3. How significant are gravity waves excited in the lower atmosphere: their energy deposition, their disturbance of the ionosphere (sporadic E)? How are these gravity waves related to thunderstorm activity and earthquakes? How is large-scale circulation related to topography?

4. What are the mesospheric chemical processes that determine the distribution of O and H, and how does the escape of H and H^+ (polar wind) affect the evolution of the earth's atmosphere?

5. How important is the transport of chemical energy associated with the global wind circulation to the energy budget of the mesosphere, and is it related to the winter anomaly in the mesosphere?

6. What is the cause of the semi-annual variations in the lower thermosphere? Is it solar UV heating, magnetic storm activity associated with Joule heating and particle precipitation, or non-linear coupling from the annual circulation? What is the relationship between the mesospheric and thermospheric variations, and what are the coupling mechanisms?

7. What is the relative importance of molecular diffusion induced by wind circulation above 120 km altitude and variations in the eddy diffusion at lower altitudes for the observed winter bulges in O and He? Are similar effects observed in H, and what are the implications for the geocorona?

8. How significant are the energetic processes of the lower thermosphere relative to the wind-induced diffusion process for the density-temperature phase anomaly observed in the upper thermosphere?

Chemistry and Dynamics of the Stratosphere and Mesosphere

The stratosphere and mesosphere (12 to 90 km) are difficult regions to probe because of the pressures at these altitudes. Probing has been limited to high-flying aircraft (the lower stratosphere), high-altitude balloons (up to the stratopause) and rockets (typically operating from the stratopause on up). Thus, compared to other regions of the atmosphere, research on the stratosphere and mesosphere has been limited and fragmentary. But in the past two years, interest in this region of the atmosphere has increased markedly because of the possible deleterious effects of the effluents from supersonic transports on the ozone column density. Before detailed predictions of the effects of these added gases and particulates can be made, the "normal" atmosphere must first be understood.

Scientists now realize that the composition and dynamics of the D and E regions of the ionosphere can be significantly affected by wave motions propagating upwards from the neutral, lower atmosphere. Thus, a knowledge of this lower atmosphere becomes essential to an understanding of these regions.

The following discussion is divided into three sections: Thermal Structure, Composition, and Dynamics. However, it must be recognized that these phenomena are coupled and the understanding of them must be advanced together.

Thermal Structure—The global thermal structure of the stratosphere and mesosphere is of great importance because of its role in chemical, dynamical, and radiative processes. For example, many of the reaction rates involved in the ozone chemistry are strongly temperature-dependent.

The successful use of downward-viewing IR sensors on satellites has been demonstrated from the NIMBUS 3 and NIMBUS 4 satellites. Therefore, problems of stratospheric thermal structures are not further treated in this document.

Composition—There is a pressing need for global measurements of particulates and trace gases and their motions in the natural stratosphere and mesosphere. Because of the recent interest in environmental effects, it is important to determine the global distribution of pollutants vs. altitude. High priority should be assigned to the measurement of such gases as NO, O_3, H_2O and CH_4 in the stratosphere. Other important species include CH_3, CO_2, CO, H, OH, O, NO_2, HNO_3, N_2O, HO_2, H_2O_2, and the clusters of SO_2, H_2O, etc. For the specific case of the SST pollution problem, it is quite important to determine the distribution of O_3, the oxides of nitrogen (NO_x), and the oxides of hydrogen (HO_x).

In the ionospheric D region, reliable measurements of both neutral and ionized species are urgently needed. Important neutral gases include O, O_3, NO, H_2O, H, CO_2 and O_2 ($^1\Delta$). Positive and negative ion concentration and composition measurements are crucial in D-region research. It is especially important to determine the true ambient ion composition below the electron-density ledge (shelf) situated below 80 and 90 km. Further measurements on metallic ions in the lower E region are necessary also. The role of metallic ions in producing sporadic E (and spread-F) can be rather directly investigated by releasing them from the Shuttle.

Dynamics—Motions in the stratosphere and mesosphere are very important because of their role in transporting long-lived chemical and other trace constituents. The motions significant for transport occur on different space and time scales and may be categorized as follows:

- Zonal-wind the meridional-circulation systems
- Planetary waves
- Synoptic-scale (~100–1000 km) and mesoscale motions
- Gravity waves

Gravity waves and turbulence apparently mix and dissipate the synoptic-scale motions.

Global measurements of stratospheric and mesospheric motions vs. altitude are essential to a proper theoretical understanding of these motions. Moreoever, numerical models must be tested against actual observations of these motions. In essence, we need a reliable description of atmospheric transport processes in the stratosphere and mesosphere. These processes and their variability in space and time must be understood. Clearly, observations of transport processes can aid our understanding of atmospheric dynamics. In particular, information on the horizontal variation of vertical motions would be quite valuable.

Thus, the major questions on the stratosphere and the mesosphere which must be answered are as follows:

1. What is the chemistry of the normal stratosphere?

2. What are the relevant roles of the chemistry, dynamics and radiative processes in the stratosphere and mesosphere?

3. What are the altitudinal, global, and temporal variations of stratospheric and mesosphere temperatures? What is the intensity and temporal variation of the solar flux at wavelengths between 1-100 Å and 1000 - 7000 Å?

4. What are the vertical distributions of the minor atmospheric species, what processes control these distributions, and what role do these species play?

5. How are the aerosols distributed with height, and how are they formed? What effect could they have on the chemistry of the stratosphere?

6. What are the dynamics of the mesosphere and stratosphere? What roles do zonal winds, meridional-circulation systems, planetary waves and gravity waves play?

Physics of the Dynamo-Region

One of the basic geophysical problems is the determination of the contributions of various sources to the magnetic field variations observed at the earth's surface. The magnetic field has three contributors:

- The field associated with internal sources in the earth
- The field directly associated with external sources such as from the dynamo region of the thermosphere and from the magnetosphere
- The internal field induced in the earth's interior by the external processes

The separation of these components of the geomagnetic field variation is greatly complicated by their interaction and by the lack of simultaneous measurements at their sources. Knowledge of the winds in the dynamo region, of the magnetospheric processes, and of the current systems will enable us to separate out the contributions to the magnetic field variations at the surface of the earth. Thus, this will enhance our understanding of the nature of the interior of the earth and processes occurring therein.

The following questions need to be answered:

1. What are the current systems which are the sources of the magnetic variations seen on the ground, and how do they vary with time and latitude?

2. What are the altitude variations of the electrical conductivities at high, middle, and equatorial latitudes?

3. How do the electric fields spread out in space from these current systems?

4. How do the electric fields move plasma in the "motor" regions?

5. What are the long-period variations in the earth's interior magnetic field and how do these affect the inner magnetosphere?

PLASMA PHYSICS IN SPACE

Background

The Shuttle Sortie missions provide a unique opportunity to investigate fundamental and applied plasma physics phenomena that are not necessarily or specifically related to geophysical problems. All the Shuttle orbits are immersed within a natural, magnetically-confined plasma in a high vacuum, with scale lengths that can be enormous in comparison with those available in ground-based plasma laboratories. It is possible to investigate important phenomena free of the sometimes dominant influence of walls. The weightless orbital conditions are extremely important to the potential experimenter who may wish to study such diverse phenomena as long-term plasma confinement in a field produced by a levitated magnet, the interaction of a spinning conducting fluid with the ambient geomagnetic field and plasma, or the behavior of convection-free plasma arcs. In the ground-based laboratory all of these studies would be strongly affected by gravity.

In some general areas the availability of one or more of these unique space laboratory conditions is of vital importance. For instance, some information on low-frequency electromagnetic wave modes in a magnetized plasma (whistlers) can be obtained in a ground-based laboratory, but the conventional experiment is essentially restricted to near-field analysis for the specific wave modes allowed in the fixed and finite plasma chamber. Because of this, it is not possible to study the complete warm plasma dispersion relations or generalized radiation processes and wave-wave coupling effects in the ground-based laboratory. In some cases the finite chamber-size restrictions limit the accessible interactions and preclude study of basic plasma phenomena that are known to occur in nature. For instance, while it may be stated that non-linear beam-plasma interactions have frequently been studied in ground-based laboratories, the finite scale size dictated by laboratory chambers means that the short wavelength electrostatic waves play a predominant role in these experiments. However, the various beam-plasma dissipation processes that occur in nature appear to give rise to intense electromagnetic radiation fields (auroral hiss, solar radio bursts, Jovian decametric radiation, pulsars, etc.), and these mechanisms cannot be studied adequately in small plasma chambers.

The Sortie laboratory missions can also provide the scientific community with significant opportunities to carry out short-term experiments involving development and testing of new diagnostic devices and investigation of new techniques for plasma propulsion. Long-standing questions involving the plasma physics of the wake and sheath and the behavior of various probes in earth orbit can be studied during the Sortie missions. Some specific characteristics of the Shuttle-Sortie opportunity make these studies appropriate. In particular, the presence of man in the laboratory will make it possible to carry out true experiments rather than data-gathering exercises based on use of inflexible automated rocket or satellite payloads. Moreover, the fully-equipped laboratory facility will provide much more comprehensive information than any series of rocket launches, but the experiment costs can be kept low with use of the facility concept and with the relatively short duration of the mission.

General Plasma Physics

In the section entitled "Magnetosphere and Auroral Dynamics," above, a number of outstanding plasma physics problems were discussed within the framework of a program to investigate the space environment of the earth. However, almost all of the outstanding problems described in that section (and many atmospheric problems discussed in the section entitled "Aeronomy") involve basic plasma physics questions that are of fundamental importance even without reference to the geophysical context. In addition to those specific problem areas discussed in "Magnetosphere and Auroral Dynamics" some outstanding general plasma physics questions that can be investigated on the Shuttle-Sortie missions include the following:

1. What are the wave modes that can propagate in the space plasma? To what extent are these modes purely electromagnetic or electrostatic? What are the spontaneous growth and decay mechanisms of these modes?

2. What are the resonances in a magnetoplasma? What power levels are needed to excite them, what volumes resonate? How are the resonances affected by spacecraft sheaths and magnetic fields?

3. How do the wave characteristics vary with wave amplitude? At what level do non-linear effects become important? What types of parametric plasma instabilities are possible?

4. Can the expanded time scale available in space allow the experimenter to carry out non-steady or transient experiments that cannot be performed in conventional ground-based plasma laboratories? Can one obtain new basic information on the evolution of the distribution function in the presence of a perturbation, on particle confinement in a magnetic field, and on the temporal development of non-linear phenomena?

5. Can one utilize the unbounded, uniform and nearly collisionless plasma outside of the Sortie laboratory to conduct new types of experiments that require large volumes (i.e., those involving cyclotron damping) or the absence of external walls (i.e., some beam-plasma neutralization studies)?

6. Can one investigate resistive wave-particle interactions and the validity of various approximations to the Fokker-Planck equations in the space plasma?

7. Can basic ideas on long-delay echoes, propagation of wave packets in a dispersive medium, and three-wave interactions be studied by remotely-placed transmitters and receivers in earth orbit?

8. Can solar flare radiation mechanisms be modeled and associated mode-mode coupling be investigated?

9. Can one take advantage of the zero-g conditions to conduct new types of plasma physics experiments such as those involving steady-state Levitrons and convection-free arcs? Can one explore MHD phenomena using artificially deployed conducting fluids?

10. Can one directly investigate important neutral gas-plasma beam interaction phenomena, such as the role that the gas ionization potential plays in determining the plasma temperature? Can new information on astrophysical questions such as the interaction of a comet with the solar wind plasma be obtained in this way?

11. How much electromagnetic energy can be pumped into a magnetoplasma from a simple antenna at very low frequencies before self-limiting occurs due to non-linear effects?

Wake and Sheath Studies

A fundamental problem in plasma physics involves the analysis of the region of disturbance around a body placed within the plasma. Even for a body at rest a complex and poorly-understood charge separation or plasma sheath region develops, and as the plasma flows past the body, a wake region is also formed. It is important to study the interactions of plasmas with bodies of various characteristics in order to understand a number of significant solar system problems such as the interaction of the solar wind with the moon, Mercury, comets, and asteroids. It is also necessary to study the wake-sheath in a definitive manner in order to understand the interaction of the space plasma with a spacecraft and its scientific instrument complement. The Shuttle Sortie laboratory system provides a unique opportunity to conduct well-conceived and unambiguous studies of wake and sheath characteristics. Some outstanding questions suitable for investigation include the following:

1. Can the wake and sheath regions around known deployed targets be mapped using suitable diagnostic instruments mounted on a remote maneuverable platform? Can the validity of current theories be tested by a comparison of predictions with measurements of the size, shape and potential distributions in the perturbed region? What are the effects of varying the target shape and the target surface material?

2. How stable is the wake and sheath region? How does this stability change when the target is biased? Do Cerenkov cones develop in the wake region?

3. How are phenomena such as antenna impedance and the response of plasma probes affected by the non-linear characteristics of the wake and sheath?

4. Can large-scale Terrella experiments be conducted in space using strong deployed magnets?

Diagnostic and Propulsion Device Studies

The Shuttle Sortie laboratory facility can be used to develop and test new diagnostic and propulsion devices as well as to resolve long-standing questions involving operation of various conventional probes. Some pertinent questions suitable for investigation include the following:

1. Can the well-known problems of Langmuir probes, Faraday cups, and DC electric field measuring systems be resolved by conducting short-term but well-conceived intercomparison experiments in space?

2. Can promising new propulsion devices, such as the magneto-plasma-dynamic arc, be tested and perfected in the unbounded space plasma without the distortions known to be produced on earth by finite chamber size and gravity? Can phenomena such as plasma-beam and ambient-plasma interactions be studied and developed for ultimate propulsion applications?

3. Can new techniques for measuring small plasma drifts, DC electric fields, or other important quantities be tested and developed during short-term Sortie missions?

Other Plasma Physics Applications

The field of plasma physics is a rapidly developing one; thus, it is certain that by the end of the 1970's there will be a host of new problem areas suitable for direct investigation in the space plasma. It can be anticipated that there will be a similar change in the needs with respect to applications studies. One type of input comes from the field of radio astronomy, as ground-based observers continuously detect new types of interacting plasmas by analyzing the electromagnetic radiation characteristics. It can be anticipated that in the 1980's there may be widespread desire to model diverse phenomena such as solar radio bursts, outer planet radiation mechanisms, and pulsar wave generation processes. As noted previously, since these phenomena all probably involve some sort of coupling between the long wavelength radiation field and short wavelength plasma oscillations, it is unlikely that much progress can be made in the bounded confines of any ground-based plasma laboratory. In general, it should be recognized that the magnetosphere and ionosphere represent the most accessible laboratory for the observation of physical processes and the performance of experiments which have relevance to phenomena that take place on the planets, the sun, and the stars. The phenomenon of fast release of stored magnetic energy taking place in the neutral sheet may represent the closest example of the basic process that occurs in solar flares. The acceleration of particles to suprathermal energies constitutes a phenomenon which is taking place on the sun and the stars and has broad relevance to the studies of solar physics, astrophysics, and cosmic rays. Similarly, the generation of electromagnetic waves and the wave-particle interactions seen in the magnetosphere have corresponding counterparts in phenomena observed on the sun and some of the planets. Clearly, the study and understanding of physical processes operating in the magnetosphere are of essential value to the understanding of such processes operating at larger scales in other parts of the solar system and the universe.

MAJOR EXPERIMENT CONCEPTS FOR ATMOSPHERIC AND SPACE PHYSICS

ACTIVE EXPERIMENT – SHUTTLE AS OBSERVING PLATFORM

The release of a tracer (e.g. lithium) outside the magnetosphere, and the use of a Shuttle with diagnostic instruments and sub-satellites to record its subsequent motions may be able to resolve directly the question of what fraction of the solar wind enters the forward magnetosphere near the neutral points, and what fraction enters through the tail. Measurement of the ionized lithium will be through particle detectors and photometers. The most intense lithium line in the singly ionized state is at 199 Å, so that photometric observations cannot be made near the ground. More restricted entry problems can be studied by releasing tracers in the magnetotail, or in the polar cleft regions. If a dedicated module can be made available for Atmospheric and Space Physics, this class of experiment would greatly benefit from an on-board capability for launching the vehicle which is to release the tracer.

ACTIVE EXPERIMENT – SHUTTLE AS SOURCE

The Shuttle can "paint" a significant fraction of an entire orbit with chemicals such as barium or helium. Observation of such a trail, using aircraft and ground-based cameras, could provide in one day more information on global circulation than years of sounding rocket releases. Both neutral and ion winds can be studied, and temperature data can also be obtained.

The use of electron accelerators to generate artificial auroras could provide definitive answers to significant questions concerning acceleration mechanisms and plasma instabilities. Ground-based and aircraft observation stations would be needed, and rocket flights could also provide useful diagnostic data. The same accelerator in the "electron echo" mode can provide data on magnetic and electric fields integrated over long paths. One very important application here will be the use of electron beams, stepped or ramped in energy, and operated in both reflection and transmission modes, in order to determine the electric potential drop along entire magnetic lines of force.

SHUTTLE AS A PLASMA LABORATORY

The stimulation of plasma resonances with an on-board transmitter can provide rapid answers to questions concerning the critical power levels, the interaction volumes, and the resonant (Fourier) structure if a maneuverable sub-satellite is used as a probe.

The behavior of an antenna in a magnetoplasma can be explored in the same manner. In particular, there are practical problems which cannot be modelled on the ground. For example, it is of great interest to determine the amount of power which can be pumped into an antenna before the process becomes self-limiting due to non-linear effects. This if of special interest at very low frequencies. Here, a wire antenna many kilometers long can be unreeled from a sub-satellite, and a number of plasma and radio frequency regimes investigated in a short time.

SHUTTLE AS PERTURBATION

The wake behind the Shuttle can be mapped with a maneuverable sub-satellite. Both the real wake (including outgassing) and the wake from a clean test body can be investigated in detail.

SHUTTLE AS AN ATMOSPHERIC SCIENCE FACILITY

Gaseous reactions and excited states can be investigated by releasing appropriate quantities of gas. These can be excited by the sun, by lasers, or by beams of electrons. Chemical reactions important to the atmospheres of other planets, or comets, can be investigated using the appropriate gases. Conversely, the lasers and electron guns on the Shuttle can be used to excite existing terrestrial constituents. For long-lived excited states, it may be appropriate to observe the effects at some distance, from a sub-satellite. Otherwise, the diagnostic equipment can be on the same Shuttle.

SHUTTLE FOR WAVE-PARTICLE INTERACTIONS

The Shuttle provides a versatile platform for investigating a wide range of wave-particle interactions. The waves may be generated on board, to interact with ambient particles; or particle streams may be generated on board to interact with radio waves transmitted from the ground. The interactions which have been suggested range from the weak perturbations which trigger VLF emissions to the strong interactions which could produce significant perturbations in the radiation belts.

SHUTTLE AS A CIRCUIT-BREAKER

By releasing electron acceptors (such as sulfur hexafluoride) over strong ionospheric current systems, it should be possible to reduce conductivities sufficiently to stop the equatorial or auroral electrojet for times of the order of minutes. If the effects are observed from the ground and from sounding rockets, the basic mechanisms of these current systems can be much better understood.

SHUTTLE AS A PRECIPITATOR

It has been pointed out by a number of workers that conditions often exist in the magnetosphere under which the addition of small amounts of cold plasma at appropriate locations will result in rapid growth of wave instabilities and produce subsequent dumping of large amounts of trapped particles into the atmosphere. Several Shuttle experiments are envisioned in which canisters of 20-40 kg of light gases are released just inside or just outside the plasmapause to explore the question of whether tubes of magnetic flux can thus be emptied of their energetic particle contents for short periods of time. These experiments, if successful, will point the way toward active control of the radiation content in the Van Allen belts.

CANDIDATE PROGRAMS

INTRODUCTION

Following the traditional discipline lines, three studies were begun in 1970-72. Each study collected ideas and concepts from broad segments of the scientific community. These studies, their contractors, and the responsible NASA centers are as follows:

- Plasma Physics and Environmental Perturbations, TRW Corporation, Marshall Space Flight Center
- Atmospheric Science, Martin Marietta Corporation, Johnson Space Center
- Auroral Science, the University of Alaska, Johnson Space Center.

The studies were performed independently, and yielded a diversity of ideas for science planning. One striking common factor emerged at an early stage, however. That was the concept of a dedicated laboratory or facility, with large core instruments which could be flown many times to perform different experiments, together with smaller individual instruments which could be taken on or off to fulfill the peculiar requirements of each flight. Great economy of operation could be achieved, therefore, by the repeated use of each dedicated module with only minor modifications per flight. The studies were renamed, according to the purposes of each of the required dedicated laboratories, as follows:

- Plasma Physics and Environmental Perturbation Laboratory (PPEPL)
- Atmospheric Science Facility (ASF)
- Magnetosphere and Auroral Manned Observatory System (MAMOS).

When the Atmospheric and Space Physics Working Group came into being in late 1972, it was soon realized that elements of the three facilities could profitably be combined into one module. Not only would the Shuttle accommodate all three, but, much more important, their conjunction provided a synergistic rush of new ideas which had been prevented from surfacing due to the artificial constraints of the discipline boundaries. It was seen, for example, that the electron gun on the PPEPL could provide an electron excitation source for ASF and MAMOS; that the active experiment concept of PPEPL enabled atmospheric reactions to be studied when gas release cylinders and lasers were added; and that the MAMOS observing instruments could provide a splended means for observing the effects of tracer injection and modification attempts.

The next section (Core Instrumentation p. 36), lists the major items of core instrumentation which have been identified from all three studies. Many of these instruments were common to all the studies. Using these core instruments as building blocks for laboratories, we then show three distinct laboratory configuration (see page 43) optimized for Plasma Physics and Environmental Perturbations, Atmospheric Sciences, and Auroral Sciences. In the section entitled "Relevance of the Planned Scientific Program to Other Disciplines" (page 60) we show some of the relationships between studies made possible by these laboratories, some of the interests of other disciplines of science, and some applications of these studies.

In order to perform most of the experiments which have been suggested thus far in these laboratory configurations, a flight program on the order of four Sortie flights per year over the decade of the 1980's is required, if each flight is assumed to be seven days in duration and two crew members are available to perform experiments. Thus, a logistics analysis indicates that one or two dedicated Sortie laboratory shells will be required, and two pallets for instrument mounting. This would permit a six-month turn-around time for refurbishment of each laboratory between launches. The Group believes that such a program, when supplemented with the necessary ground-based, airplane, and rocket facilities, should be able to answer most of the key scientific questions for the 1980's raised in the section titled "Scientific Discussion" (page 4).

CORE INSTRUMENTATION

The following major pieces of equipment are considered to be the core instruments for the Atmospheric and Space Physics Shuttle Laboratory in the 1980's:

Long Boom Assemblies

In order to carry out many experiments, especially those involving low-energy plasmas and small-amplitude waves, it is very frequently required that active perturbing and sensing equipment be remotely located from the large Shuttle-Sortie lab system. The proposed experiment concepts have been examined in detail, and it has been concluded that more than 60 percent of the scientific objectives for about 110 candidate experiments can be satisfied with a Sortie lab design that includes only two 150-foot long maneuverable booms. Thus, although the science return is fully optimized only with deployment of a maneuverable sub-satellite (see "Sub-satellites" p. 40), a viable and significant configuration for early missions involves only the two booms.

The present conceptual design is based on use of two retractable 50-meter booms of the Astromast variety, mounted on swivel platforms so that the extensions and relative orientations may be controlled from within the Sortie laboratory. Boom number one is the passive or diagnostic boom, and it contains a full array of equipment to diagnose the ambient plasma characteristics (density, temperature, composition, suprathermal particle population) as well as the ambient vector dc magnetic field, one axis of the dc electric field, and the electric and magnetic components of local plasma waves. A possible configuration is shown in Figure 3. Two small (5-meter) retractable sub-booms are used to remove the field-measuring sensors from the particle detectors in order to minimize EMC and magnetic contamination. Some items in this figure require additional explanation:

1. The one-meter loop is supposed to be a Mylar balloon of the type flown on several OGO spacecraft. This loop is inflated by a gas bottle and is ejected before the boom package is retracted.

2. The rubidium magnetometer is presently included because a number of candidate investigators requested a continuous and accurate measure of the local electron gyrofrequency, primarily in order to tune the transmitter for various RF sounding experiments.

3. The alignment TV camera will be used to point the instruments on boom number one toward the active or exciting elements on the second boom or on the pallet.

4. In order to minimize cabling along the retractable 50-meter boom, it appears expedient to have the power supply and an encoder-multiplexer mounted at the end of the boom.

The second boom is the active one, and it is planned that for any given flight, CORE equipment will be selected to carry out the designated experiments, or experiment-unique equipment will be provided by the investigator. A possible configuration for boom number two would contain the following:

- A low-energy (5-20 eV) electron gun to measure E parallel to B and to study low-energy beam plasma streaming instabilities

- An electrostatic plasma wave generator for boom-to-boom transmission experiments

- Various targets for wake-sheath studies.

These targets might be balloons with variable shapes and surface materials, capable of being biased electrically with respect to the plasma.

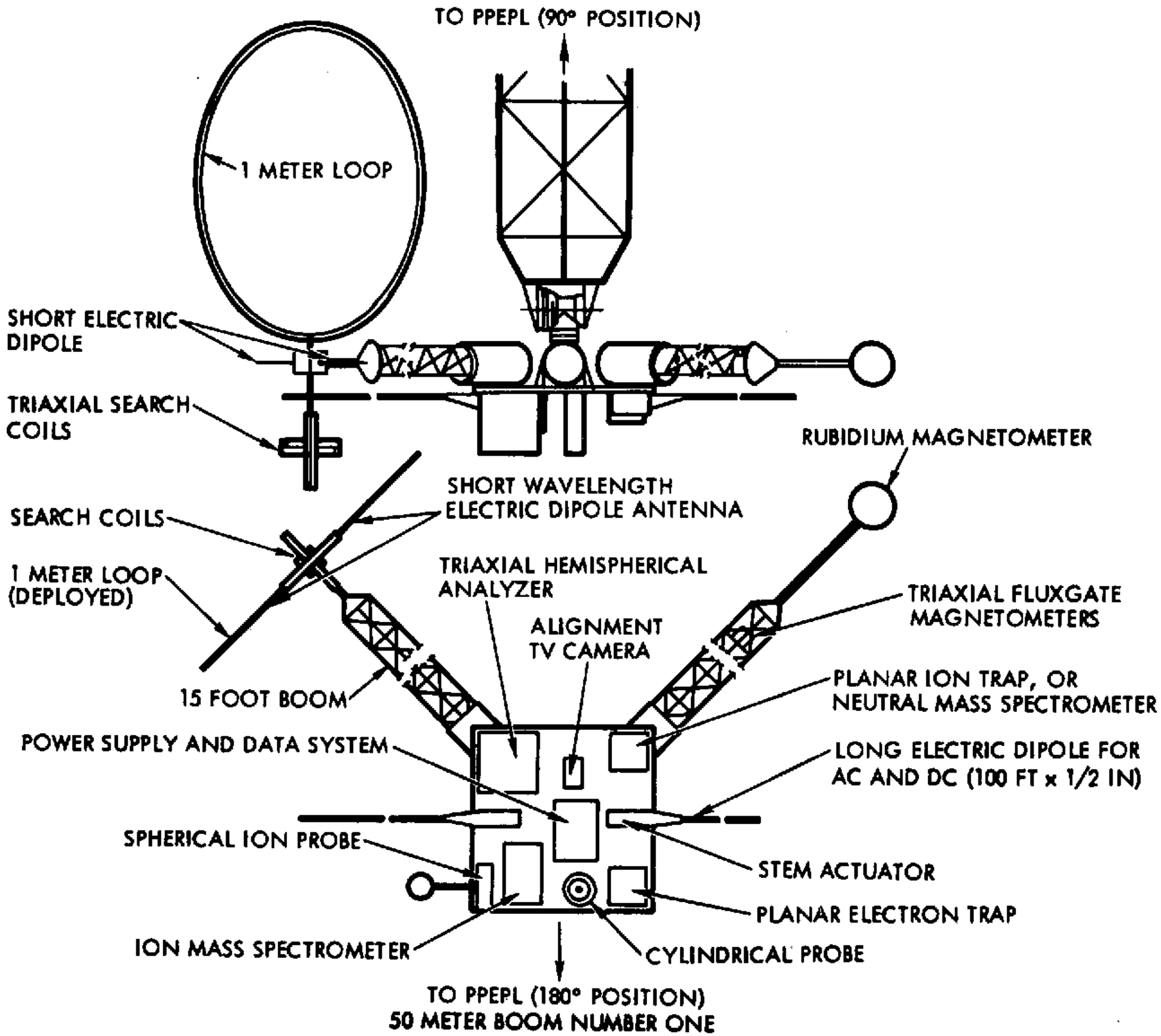


Figure 3. Long Boom Assemblies

Electron and Ion Accelerators

A tentative accelerator group configuration under study for initial PPEPL flights consists of an electron gun, an ion gun, and a plasma accelerator. The likely element for use as an electron gun is a congruent-flow cylindrical-geometry Pierce-type accelerator. The desired gun perveance is 10^{-6} amps/volt$^{3/2}$ yielding a 1-ampere output at 10 kilovolts. Desired initial gun operational range is 10 kilovolts to 50 kilovolts. The likely element for the proton gun is a multi-aperture electron bombardment ion source with an initial desired output of 1 ampere at 50 kilovolts. Desired abundance of H^+ is 75 percent of the ion flow for hydrogen operation. Operation on all other noble gases and on N_2 is possible. The likely element as a plasma accelerator is a magnetic-plasma dynamic arc. This plasma device is inherently adaptable to pulsed operation and possesses a wide range of possible output power. Such a device would allow high-energy plasma deposition onto a field line in milliseconds. We also plan to be able to mount a low-energy (5-20 eV) electron gun on the end of the active boom, as discussed above, under "Long Boom Assemblies," p. 36.

Large Gimbaled Platform

The gimbaled platform is a circular disk approximately eight feet in diameter which provides common power, data, and control interfaces to accommodate a variety of diagnostic instruments requiring pointing. These instruments will be mounted on the platform and used in the analysis of ambient plasma parameters and perturbed phenomena.

Typical instruments to be found on the platform will include spectrometers, photometers, and particle sensor clusters. The platform may also be used to test various types of new instrument concepts and for comparison of various diagnostic instruments. The dish is controlled by an accurate servo-motor which will provide a scanning and stable-viewing capability to instruments mounted thereon. The platform itself will be attached in the approximate center of the Sortie Lab pallet.

Chemical and Gaseous Releases

Several ejection devices need to be employed to launch canisters containing chemicals and several types of gases from the Sortie Lab pallet. In most cases we expect that these devices will be spring-ejected; however, in some instances (e.g., when separations from the Sortie Lab ranging up to hundreds of kilometers are required), rocket launchers may be needed. The canisters to be deployed will contain chemicals (such as barium or SF_6) for release into the magnetosphere, or selected gases for release into the upper atmosphere; or they could contain inflatable wake bodies to provide well-defined targets with simple geometry for plasma-wake and sheath investigations. A few of the chemicals required are extremely corrosive; thus, unless proper safety techniques are used, these chemicals could be a source of serious contamination to the Sortie Lab. It may prove wise in some cases to use coordinated sounding rocket launches for these releases instead of launching them from the Shuttle.

Transmitters

A high-powered radio transmitter mounted on the pallet will be used to modulate long sounding antennas (up to 1000 feet per element, as on Radio Astronomy Explorer). It is possible that HF and RF potential amplitudes up to 20 kilovolts will ultimately be needed to drive the antenna. The Alouette and ISIS transmitters already have put out several kilovolts at their frequencies, and the 20 keV requirement is not a significant extension of existing technology. The major present uncertainty in this area concerns the low frequency limit for the high-power transmitter. At frequencies well below the local electron plasma and gyrofrequencies, some problems involving tuning, sheath effects, and dipole unbalance arise. It would be wise to devote some SRT support to this important area in the next few years, in order to prepare for a PPEPL experiment program on the generation of large-amplitude low-frequency waves.

It has been proposed that lowest frequency (ELF and ULF) electromagnetic plasma waves can be generated by phased arrays of electron and proton guns, and this investigation should be carried out at an early stage. For early missions we do not anticipate using normal or superconducting loop antennas for wave generation, but this may prove desirable at a later stage.

Sub-satellites

Although a significant number of experiments can be performed without the benefit of sub-satellites, their addition greatly enhances not only the number of experiments that can be performed, but also the depth to which most experiments may be carried. Sub-satellites broaden the spatial domain over which experiments may be carried out, and the increased distance also increases the time available for performing experiments. With sub-satellites it will be possible to study characteristics of long-wavelength plasma waves and to perform remote studies such as magnetic conjugate-point investigations which could not be performed without these systems.

The small sub-satellites can be simple diagnostic platforms which are launched into the magnetosphere from the Shuttle to provide continuous remote data on plasma parameters. Active experiments performed from the Shuttle will then take advantage of the location of these sub-satellites in obtaining parametric data.

Controllable sub-satellites, which can be maneuvered to a variety of locations to carry out continuous cause-and-effect observations, can also be deployed. These platforms may be moved to the precise locations called for by the particular experiments. They can be used in search mode to locate particle or wave effects, and also to define the spatial extent of phenomena and varying boundary conditions of importance. Aside from free-flying sub-satellites, we also contemplate the deployment of remote tethered platforms. These sub-satellites or tethered platforms will generally require many of the passive diagnostic sensors shown in the drawing of boom number one (Figure 3).

A major requirement in this area is for a large sub-satellite to be injected into an elliptical polar orbit (300-minute period) during one of the polar Sortie missions. This sub-satellite, containing downward-viewing shuttered auroral imaging devices and a variety of particle and field detectors, will obtain comprehensive views of the entire auroral oval during simultaneous auroral zone crossings of the Shuttle Laboratory. Thus, it is the key to the next major advance in our study of the auroras. This sub-satellite may be similar in size and capability to the current Atmosphere Explorer spacecraft, which has already been built, and can be duplicated at minimal cost. The Atmosphere Explorer spacecraft, with its propulsion capability and the spin-up and spin-down facility, is well suited to perform a variety of the tasks currently envisaged. It should certainly be considered as a candidate for the core payload.

General-Purpose Spectrometers

Four general-purpose spectrometers are utilized for atmospheric and gas-release observations. These cover the wavelength range 300 Angstroms to 150 micrometers. Two are grating spectrometers to cover the range from the extreme UV to approximately one micrometer in the infrared, and two are Fourier interferometer spectrometers to cover the infrared region from one to 150 micrometers. For some purposes, spectrometers could be mounted on the sub-satellite in order to observe the effects of Shuttle-induced perturbations from a more favorable location.

Solar Instruments

Four types of solar monitoring instruments are required to perform a broad class of atmospheric and gas release cause-and-effect experiments. First, the total absolute solar irradiance should be monitored in the 0.2 to 5 μm spectral region. Secondly, low-resolution absolute measurements of the spectral distribution of solar energy over the same spectral range would be required. A third set of instruments to monitor extreme ultraviolet and vacuum ultraviolet fluxes to 5% or better absolute accuracy would be composed of several fixed wavelength and scanning monochromators covering the spectral range up to 1800 Å. Finally, high-resolution measurements of solar-line profiles in the 300 to 1800 Å region would also be necessary. These latter measurements would require only relative intensity accuracy, and would be achieved with three instrument designs optimized to the optical reflectivity characteristics of the 300 to 600, 600 to 1200, and 1200 to 1800 Å spectral regions, respectively.

Lasers

A system is invisaged involving both fixed frequency and tunable lasers in the visible and ultraviolet. Mounted on the Sortie pallet and used in conjunction with the General Purpose Spectrometers, the lasers can be used to excite transitions in the upper atmosphere, in gas releases from the Sortie, and for a great variety of other experiments. The lasers will be extremely important when used at frequencies where backscattering off clouds and dense plasmas can be observed. In this mode the lasers can probe broad regions of the upper atmosphere and space. They can perform such diverse studies as the following:

- Mapping noctilucent and tropospheric clouds
- Investigating neutral species in the ionospheric D region
- Mapping the distribution of atmospheric aerosols
- Discriminating ice crystals from water droplets at high altitudes
- Performing meteorological and oceanographic studies
- Determining cometary constituents from large distances.

The Plasma Physics and Environmental Perturbation Laboratory (PPEPL)

Introduction — The present concept of the Plasma Physics and Environmental Perturbation Laboratory was developed with the widespread participation of the scientific community, and this extensive scientific input reflects the growing awareness of the need to carry out controlled experiments in the space plasma. In November of 1971 a questionnaire, together with a brief description of possible Shuttle Sortie mission capabilities, was circulated to 280 scientists in the United States and fifteen foreign countries. This solication yielded a large number of valuable responses, and to date letters describing more than 150 distinct experiment concepts in the PPEPL area have been received from scientists in the U.S. and elsewhere (Canada, England, France, Germany, Italy, the Netherlands, Sweden, Israel, Australia, New Zealand, Japan, and India).

This information obtained from the questionnaire clearly indicated that a large number of experienced scientists are now seriously considering ways to carry out controlled experiments in the space plasma environment of the earth. The ideas for these studies first arose naturally when some early active experiments provided unplanned but invaluable information on cause-and-effect relations in the magnetosphere and ionosphere. For instance, the high-altitude nuclear explosions of the early 1960's gave new information on particle injection, wave generation, wave-particle pitch-angle scattering, and large-β effects, including turbulent diffusion. The Alouette and ISIS RF sounding experiments opened new fields involving wave resonances, wave-particle heating, wave-wave interactions, and parametric instabilities. Similarly, the triggering of magnetospheric emissions by ground-based VLF transmitters suggests an obvious generalization to a controlled satellite-borne wave-particle interaction study. In recent years, there has also been an increasing emphasis on the implementation of carefully-designed active experiment programs using ground-based transmitters, sounding rockets, and unmanned spacecraft. For example, electron accelerators were flown to produce artificial auroras, to study beam-plasma instabilities, and to analyze trapped particle orbits. In addition, radio waves were used to modify the ionospheric characteristics, and artificial tracers were used to study field line topology and particle drifts.

Because of this extensive background, most of the elements of a Plasma Physics and Environmental Perturbation Laboratory are in an advanced state of development; thus, it is suitable to conceive of PPEPL as a laboratory facility in which standardized diagnostic instruments and data processing modules are furnished as CORE equipment. Prospective investigators should be able to carry out many experiments using only CORE equipment, but provision will be made for the integration of certain experiment-unique equipment as well.

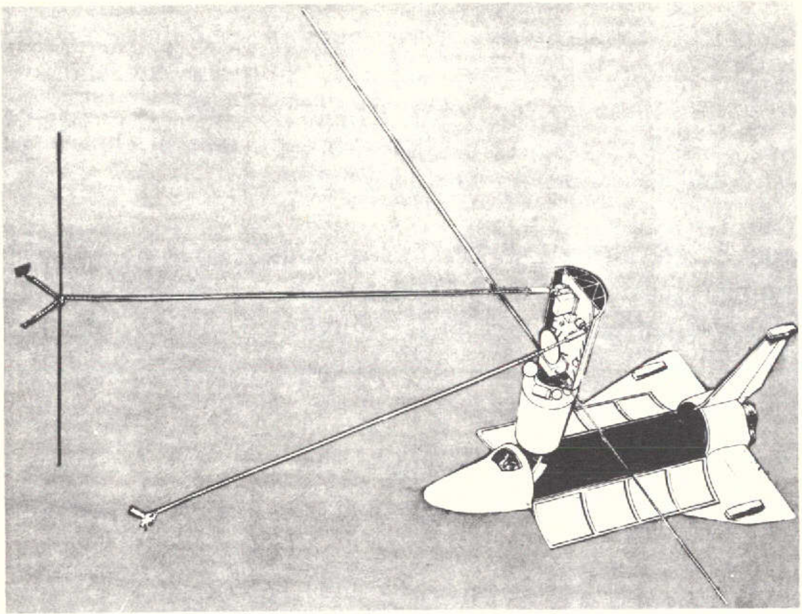
General Description of the PPEPL Two-Design Configuration — The Plasma Physics and Environmental Perturbation Laboratory concept described here (Figure 4) is housed in a fifteen-foot diameter, twenty-five foot long pressurized version of the Sortie Lab. Attached to the end of this Sortie Lab is a pallet which is thirty-three feet long and twelve feet wide. The pallet is unpressurized, and during the experiment time it is exposed directly to the ambient environment. It has been assumed that during this experiment time the Sortie Lab and its associated pallet are deployed out of the Shuttle bay and assume a position 90° (Figure 4) to the Shuttle bay while still attached to the Shuttle. Although this deployment mode is extremely beneficial for PPEPL, it should not be regarded as a mandatory requirement; it is possible to redesign the pallet package for the undeployed mode. The Sortie Lab is accessible to the Shuttle through a pressurized tunnel. As a result, the far end of the pallet is (approximately) fifty-eight feet above the Shuttle bay in the deployed mode.

Near the far end of the pallet are mounted two 50-meter deployable booms which can be articulated. There is a gimbaled platform at the end of each boom, and instruments are mounted on each of these gimbaled platforms. These instruments include antennas, particle detectors, magnetometers, and other equipment to be used for many experiments, particularly those in the areas of wave-particle and beam-plasma interactions, wave characteristics, devices, and wake and sheath measurements.

Mounted on the far end of the pallet are high-power electron-ion beam guns complete with power supply. The guns themselves are of several types, but they operate from a common power supply. On the opposite end of the pallet nearest the Sortie Lab is mounted a variable transmitter and power supply with associated dipole antenna. The dipole antenna may be extended to about 1000 feet per element once the Sortie Lab and pallet are deployed.

About half-way between the antenna and the electron-ion beam guns a gimbaled platform eight feet in diameter is mounted. This gimbaled platform contains optical and particle detectors requiring pointing. These sensors are used for a number of experiments; especially those in the areas of beam plasma interactions, magnetospheric modifications, and energetic particle and tracer experiments.

The pallet provides sufficient area to accommodate other experiment items. For example, canisters containing lithium, barium, or other chemicals may be



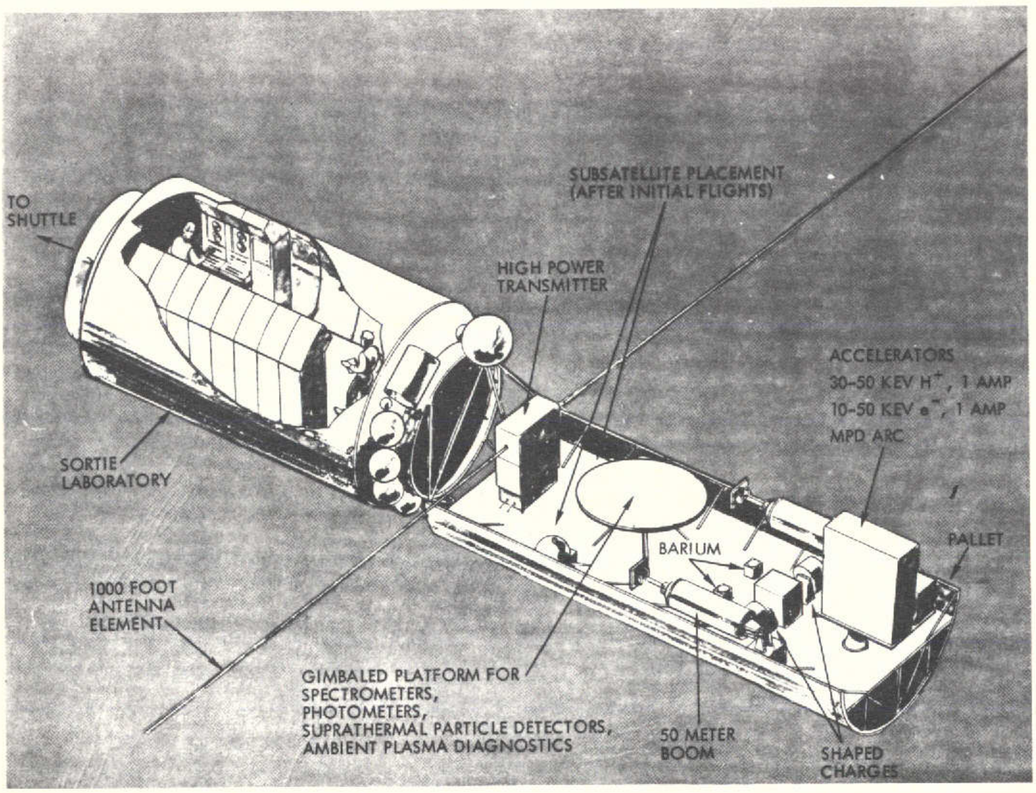


Figure 4. Two Views of the PPEPL

mounted on the pallet and ejected to carry out ionospheric wind studies, field line tracing, and electric field investigations. In a similar manner, canisters containing inflatable "wake bodies" may also be ejected, as may maneuverable sub-satellites. As can be seen, with the concept illustrated in Figure 4, some space for growth and ASF instruments is provided.

Inside the pressurized Sortie Lab are located the control and display consoles for the instruments, transmitters and receivers for the RF and VLF experiments, electron and ion beam control and display consoles, a computer, spectrum analyzers for near-real-time data evaluation, additional power supplies, general work areas, and recorders.

Baseline PPEPL Facility — The primary core instruments for the PPEPL consist of:

- Long Boom Assemblies (described on page 36)
- Electron and Ion Accelerators (described on page 39)
- Large Gimbaled Platform (described on page 39)
- Chemical and Gaseous Releases (described on page 39)
- Transmitters (described on page 40)
- Sub-satellites (described on page 40).

A suitable array of these instruments in a Sortie Lab and pallet configuration is shown in Figure 4. Well over a hundred major plasma and environmental perturbation experiments, most of them involving active pulsing of the ambient medium, have thus far been identified as possible with this array.

Telemetry Requirements — The Plasma Physics and Environmental Perturbation Laboratory opens a new era in spacecraft data management. The laboratory will be required to record some amount of passive diagnostic data per day, to record source characteristics of the planned perturbations, and to provide the user with the appropriate data for correlation. We realize that most experiments will be preprogrammed; however the intervention and innovation of the experimenter will provide a new dimension in performing experiments in space. Therefore, data formating must be devised to provide a universal reduction capability to users, and to facilitate real-time sampling during experiment operations. In addition, the data system will provide a control function for many of the instruments and support systems such as booms, power supplies, sub-satellites, etc.

Atmospheric Science Facility (ASF)

Table 1 lists the major areas of research in atmospheric physics along with the associated parameters or physical phenomena that need to be measured and the measurement techniques most frequently employed. The particular techniques to be used from an orbiting spacecraft such as the Shuttle depend, of course, on the altitudes at which the phenomena are located.

At altitudes above 120 km, both *in situ* and remote sensing techniques can be used, but below 120 km only remote sensing can be employed, whether it be by passive techniques such as observing the natural radiation from the atmosphere, or by the use of active techniques such as lasers. In the initial approach to the formulation of an Atmospheric Science Facility, the Working Group stressed a remote sensing capability, resulting in a definition of a general-purpose optical facility. However, as will be discussed later, *in situ* measurements can be performed from such a facility.

In September 1970, a conference attended by approximately forty atmospheric scientists from all parts of the United States was held at NASA Manned Spacecraft Center for the purpose of discussing the objectives for such a facility. After a period for review and comment on the preliminary conference proceedings by the conference participants, a questionnaire was distributed in January 1972, to an expanded list of scientists, eventually numbering about 130. Each scientist was requested to express his opinions of the objectives and to give a detailed description of experiments required to accomplish those objectives. At the same time, Martin Marietta Aerospace, Denver Division, was placed under contract to take these experiment requirements and perform a preliminary design study.

Since then, approximately 100 additional persons have been contacted as the study proceeded. Thus, a continuing input was maintained while the scientific community was kept aware of the developments in the program. The results of the study were presented at a review conference of atmospheric scientists in October 1972, at NASA/JSC.

Preliminary Instrumentation — A review of existing or proposed instrumentation for atmospheric research and related fields showed that virtually all of the experiments proposed by the scientists could be performed with existing

Table 1

RESEARCH AREAS	PARAMETERS/PHENOMENA	MEASUREMENT TECHNIQUES
Atmospheric Composition	Atmospheric major and minor constituents Aerosols Airglow Aurorae	IR Interferometry UV/Visible Spectroscopy *In situ* measurements Polarimetry LIDAR
Atmospheric Structure	Vertical profiles and horizontal distributions of atmospheric constituents Thermal structure (temperature profile) Airglow, auroral, and cloud morphology Aerosols Distribution of tropospheric and stratospheric pollution Ionospheric seasonal and diurnal variations	IR Interferometry Solar and stellar occultations in UV and Visible Horizon scans of IR emissions Absolute photometry of reflected solar radiation LIDAR measurements of neutral density and aerosols Photographic and video imagery Mapping distributions with UV/Visible/IR spectroscopy and photometry
Atmospheric Processes	Airglow — photochemistry Auroral emissions Aerosol formation and dissolution Atmospheric absorption of solar ultraviolet	Horizon scans of IR/Visible/UV emissions Absolute solar XUV/UV spectro-photometry *In situ* measurements Day/night variations across terminator UV/XUV absorption spectroscopy, lasers

Table 1 (Continued)

RESEARCH AREAS	PARAMETERS/PHENOMENA	MEASUREMENT TECHNIQUES
Atmospheric Dynamics	Major and minor constituent transport modes Aerosol dispersal Atmospheric and magnetospheric interactions — Auroral effects Velocities and temperatures of emitting species	Spatial and temporal variations of several types of data UV/Visible/IR line profile analyses In situ measurements and correlations of data High-spectral resolution Fabry-Perot interferometry
Radiation Budget	Solar input: total energy and spectral distribution Scattered and emitted energy Atmospheric transmissions Water vapor and temperature profiles	Pyrheliometry Low spectral resolution solar spectrophotometer UV/Visible/IR radiometry Multispectral observations of "truth site" light sources IR line profile analyses of CO_2 and H_2O bands

instrument design concepts, with the possible exception of the laser requirements. That is, the objectives considered to be of importance did not, in general, demand instruments far beyond the state of the art. Since one important concept for the Atmospheric Science Facility was the attempt to accomplish as many of the experiments with as few general-purpose instruments as possible, taking maximum advantage of the core instruments concept; the many potential instrument designs were evaluated with that in mind, and a baseline set of instrument types was identified for preliminary design.

Preliminary designs for the baseline instrument types were performed for several reasons:

- To illustrate the Facility concept in terms of actual instruments
- To identify the scope of the design problem as to instrument size, number of instruments needed, and areas requiring development
- To lead to preliminary concepts for the overall ASF configuration
- To provide a solid basis for interaction in later phases of the program.

Several factors influenced the designs, the number of instruments, and the collecting optics. Because detailed studies of atmospheric processes require that the distribution of many species be measured at the same time, the ASF must be able to acquire data simultaneously over a wide spectral range. Several instruments must be available in order to cover the entire range; therefore, implementation of this requirement involves a boresighted cluster of instruments on a pointable gimbal mount. As a result, a single collection aperture would be inappropriate for this type of observation.

Quite apart from the number of light collectors, the size of the collecting optics required would be quite small. For studies of extended atmospheric sources, the important parameter is the focal ratio of the telescope. This is by far the most important distinction between atmospheric and astronomical experiments; in fact, it is the distinction which causes astronomical "point source" experimental design requirements to be treated as secondary requirements.

Of equal importance as the requirement for extended wavelength coverage for atmospheric observations is the requirement for simultaneous absolute measurements of the incident solar radiation in both its total energy input and in its spectral distribution. Several instruments would be required to implement this requirement, and they would have to be mounted independent of the atmospheric instruments.

The present concepts for ASF instrumentation are listed below. They represent a preliminary effort to predict the scope of the Facility, and the results of the recent October 1972 Science Review Conference are reflected in them. One general result of that conference was the decision that the complement of instruments presently conceived should not be adopted as final; that every effort should be made to allow the instrument designs for a given Sortie to be fixed as close to actual launch time as is reasonably possible. With that disclaimer, the following ASF preliminary core instruments can be identified:

- General-Purpose Spectrometers (as described on page 41)
- Solar Instruments (as described on page 42)
- Lasers (as described on page 42). These will be utilized to the furthest extent that the technology of the 1980's permits.
- Special-Purpose Instruments — Several experiments involved requirements which were not properly met by the complement of general-purpose spectrometers discussed before. These requirements could be met in two ways: (1) as part of facility supplied instrumentation, or (2) by accommodating the experimenter's own equipment that he has built in his laboratory. In the consideration of the basic facility design, both approaches have been adopted.

Configurations — By carrying out preliminary instrument designs, it has been possible to develop ideas about the overall configuration for the ASF. Coupled with the observational requirements of simultaneous spectral coverage and solar monitoring, the instrument designs have led to two boresighted, independently pointable clusters of instruments. The first would house most of the atmospheric oriented instruments and the lasers and would require a zoom video on-line display of the common field of view to the ASF crew.

The arrangement of this cluster, as conceived by Martin Marietta is shown in Figure 5a. The principal feature of this arrangement is the versatility of the mounting. Instruments shown mounted in the quadrants in the figure may be exchanged for other special purpose instruments if special experiments require it. One quadrant has been left empty for the inclusion of the lasers, the design of which is still under study. Pointing control for this main instrument cluster would derive from a rate-stabilized gyro inertial reference, which would be periodically updated by star trackers.

The solar instruments would be housed in a separate cluster which would automatically acquire and track the sun; however, preset scan patterns and manual override of the automatic system would be available, as well. The arrangement of this cluster is shown in Figure 5b.

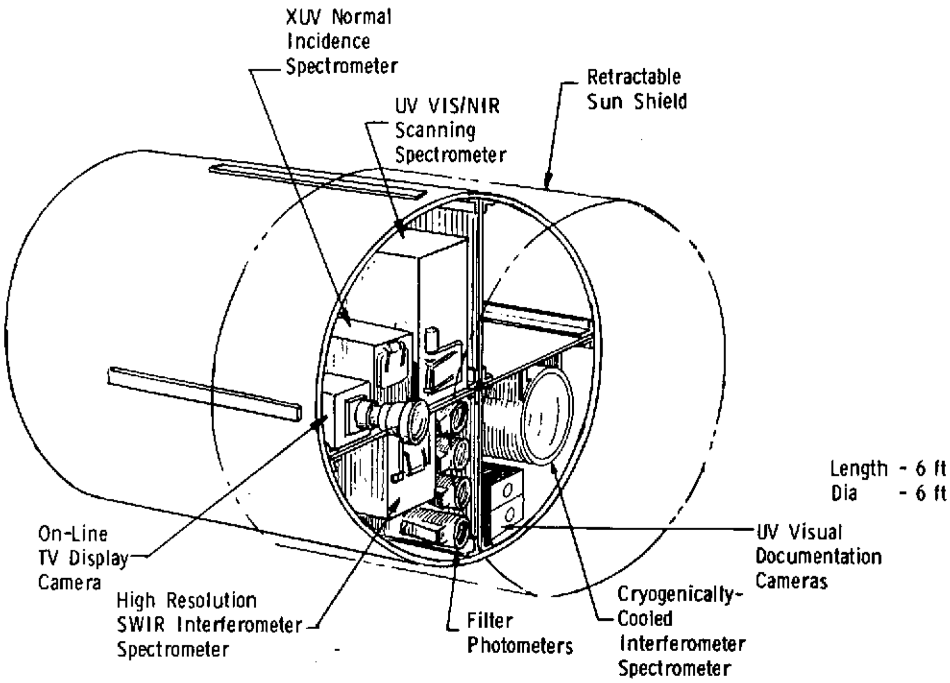


Figure 5(a). ASF Main Instrument Cluster

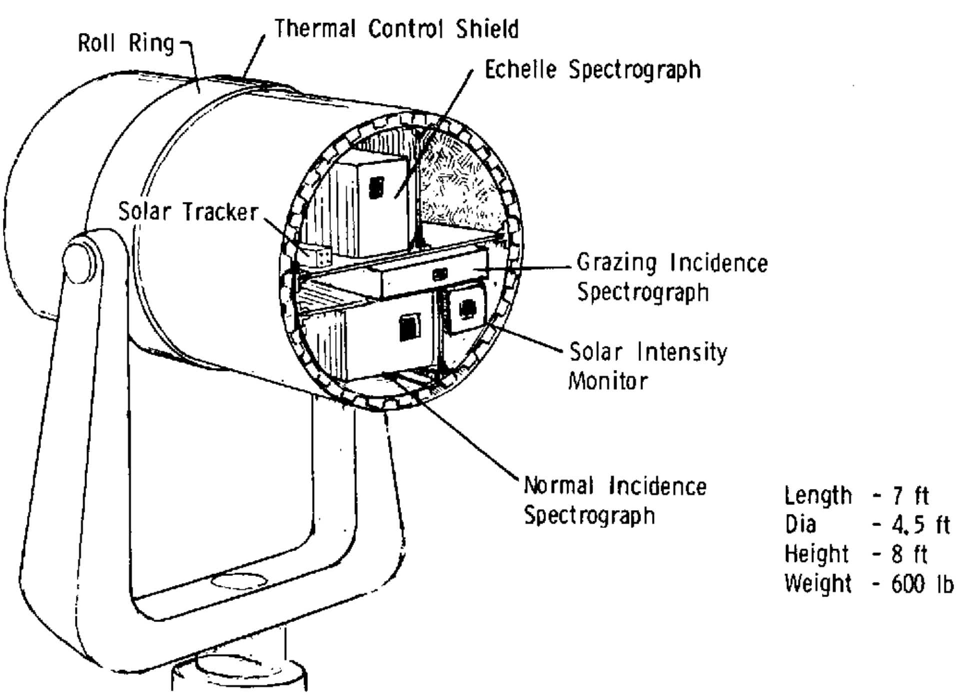


Figure 5(b). Solar Monitor and Gimbal Mount

For both of these clusters, the weight carrying capability and the available payload space of the Shuttle can be used to great advantage in that absolute standards can be carried for the calibration of instruments. This single attribute could place the ASF at the forefront of atmospheric research; hence, every effort will be made to incorporate the latest innovations in absolute radiance standards as an integral part of the instrument complement. Such an arrangement, however, need not be restricted to only the on-board instrumentation. It could also be used to update periodically the calibration of instruments on automated spacecraft, by a comparison of signals from the spacecraft and from the absolute detectors on the Shuttle facility, while both view the same source of emissions.

For acquiring upcoming targets, or for a search for transient phenomena, a third, previewing, system has been added. This previewer would provide a zoom video display to the crew, as well as the outputs of filter photometers, which provide threshold signals of desired emissions. Pointing for the previewer would be under manual control of the crew, which would derive necessary pointing information from the Shuttle navigation system.

Discussion of the best use of active laser systems has indicated the possibility that the single quadrant reserved in the Main Instrument Cluster (Figure 5a) for lasers may not be adequate. In such a case, a fourth gimbal mount to house these instruments and their collecting optics would be added. The laser system, employing both fixed-frequency and tunable lasers in the visible and the ultraviolet, will be used for such tasks as the following:

- Studies of spatial distribution, time variation, and particle-size distributions of aerosols

- Identification and distribution of natural and artificial pollutants

- Studies of nucleation processes

- Studies of the distribution and structure of tropospheric and noctilucent clouds

- Experiments in upper-atmosphere chemistry using laser-Raman techniques

- Discrimination between ice crystals and water droplets at high altitude

- Studies of water temperature from inelastic backscatter at air-water interfaces and other oceanographic studies

- Experiments in single- or double-pass absorption spectroscopy with remote ASF sub-satellites.

In addition, as mentioned previously, some in situ measurements can be performed. The instrumentation would probably be placed on a boom, such as the passive boom described on page 36, to remove it from the effects of possible spacecraft contamination. This instrumentation has not been defined at this time, but could include high-sensitivity, high-resolution mass spectrometers. These in situ measurements of the ambient atmosphere, particle fluxes, and fields would add further to the complement of ASF instrumentation. An additional gimbal mount for detector arrays (page 39) sub-satellites (page 40), and remote maneuvering devices are all possible additions to the configuration of the Facility.

The Shuttle payload bay would contain the various ASF instruments. Early missions of the Facility could have the necessary control panels and data-handling equipment housed in the crew cabin of the Orbiter (see Figure 5c). A configuration which emboides all of the ideas which have been considered in this study places the ASF control center in a shirtsleeve environment module within the payload bay, as well. This concept realizes the maximum flexibility for an effective and functional Atmospheric Science Facility (see Figure 5d).

That a rather simple complement of instruments, derived from state-of-the-art components, could be defined for the facility is probably an artifact. It could merely reflect a filtering process by the scientific community based on their knowledge of current instrument capabilities. However, the Working Group feels that the study does indicate that the basic design of a set of core instruments, to be supplied with the Facility, plus the addition of special purpose instruments which could be supplied by the investigators, is a valid approach.

Research problems of both a fundamental and practical nature would be addressed by this payload, utilizing the unique attributes of the Shuttle delivery system of large payload weight and volume, ample electrical power, several navigational and data handling services, and the flexibility created by having man on board. An atmospheric studies program of this sort would provide a coordinated attack on current problems in atmospheric research; it promises significant advances in our knowledge of the atmosphere over the decade of the 1980's.

Magnetosphere and Auroral Manned Observatory System (MAMOS)

The Magnetosphere and Auroral Manned Observatory System was designed on the basis of an examination of the current state of knowledge of magnetospheric

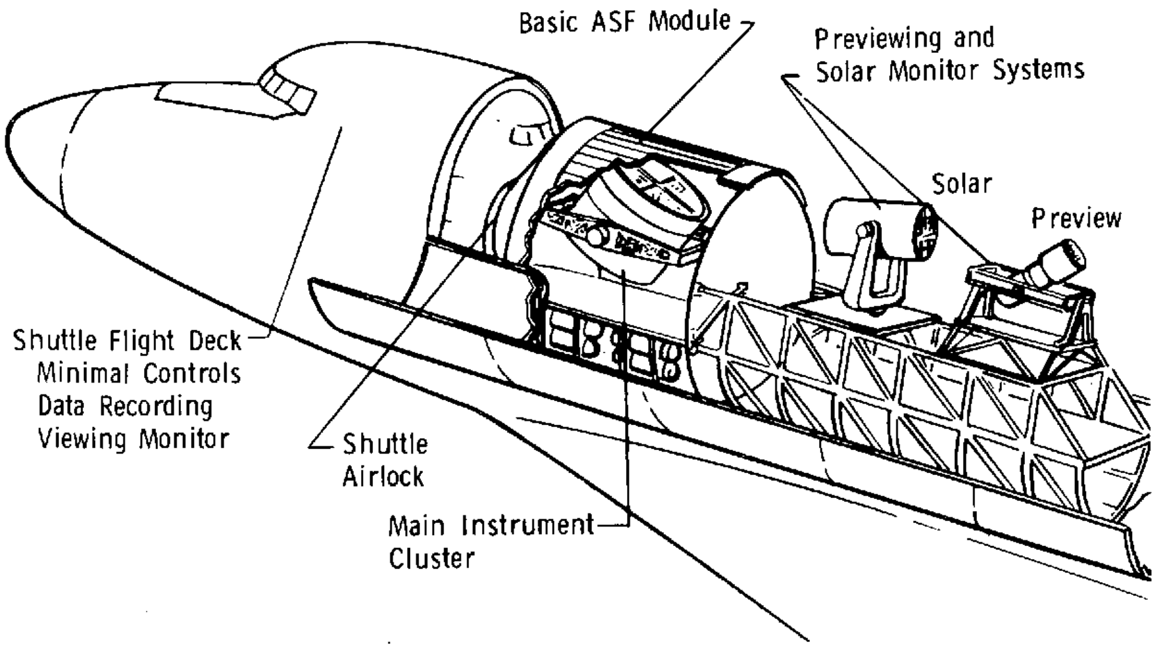


Figure 5(c). Development Configuration with Enclosed Module

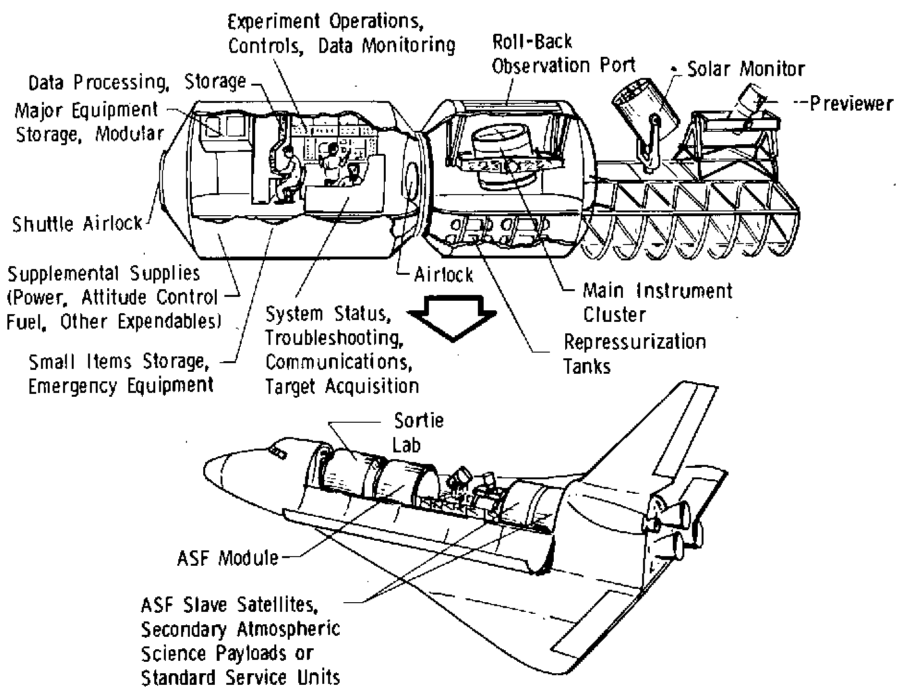


Figure 5(d). ASF/Sortie Lab Integration

physics and the outstanding problems in this field. The problems are numerous and varied but they can be characterized by the fact that they deal mostly with the dynamical behavior of the magnetosphere and its coupling with the ionosphere and the interplanetary medium. Little real understanding of the nature of the processes exists, yet we know enough to realize that dynamical behavior is the essence of the magnetosphere. Thus, a definitive understanding of these processes is the primary goal of the MAMOS. By virtue of the capabilities of the Shuttle to carry large weight and men into polar orbit, the goal of the MAMOS is realizable; in fact, major strides in understanding can be expected very early in the program.

Basically, the MAMOS is a system to use the Shuttle Sortie mode to place a sophisticated manned observatory into low polar orbit and to deploy secondary unmanned satellites in a variety of orbits for the study of magnetospheric dynamics. The main features of the system are:

- A manned observatory heavily instrumented for active pulsing and remote sensing of the magnetosphere and the auroras
- Extensive data handling and storage capability to handle very high data rates
- Capability to field massive arrays of in situ detectors on booms and on tethered or untethered platforms proximate to the observatory
- Ability to deploy unmanned satellites or probes into many different orbits
- Coordinated ground-based and sounding rocket operations.

The design of the MAMOS capitalizes upon certain known characteristics of magnetosphere dynamics and, at the same time, takes into account constraints created by magnetosphere geometry, orbital mechanics, and time scales of known or expected phenomena. In particular, it uses the fact that the atmosphere acts as a fluorescent screen upon which the aurora displays intricate, rapidly changing patterns that directly indicate the location and nature of the transient and non-equilibrium plasmas which dominate the outer magnetosphere.

Owing mainly to the high velocity of a low polar-orbiting satellite and to the rapid fluctuations of auroral events, it is necessary to make complete sets of measurements on a time scale of milliseconds if detailed relationships between related phenomena are to be understood. This necessity places a stringent requirement upon the MAMOS to provide data handling for very high bit rates from a large number of detectors and from a number of sub-satellites. A necessary part of the system must be sizable computer and data storage facilities since the rate of data flow will exceed that which is feasible or desirable to transmit unprocessed to ground acquisition stations. A major, driving reason for providing extensive data processing capability onboard the MAMOS is to allow maximal real-time or near-real-time data reduction which will reduce overall costs and increase the scientific productivity of the facility.

A variety of useful MAMOS missions, each with specific objectives, can be envisioned. However, the initial design study has given considerable attention to a mission called the "Key Mission" of the MAMOS. This mission illustrates how the MAMOS concept can be used to provide a major increase in our understanding of magnetosphere dynamics early in the Shuttle program. The need for this mission derives naturally from the examination of key outstanding problems and Shuttle capabilities.

The MAMOS Key Mission is directed toward solution of the major problem of defining and understand the characteristics of magnetospheric substorms, and the first really comprehensive study of the auroral oval. Major problems are:

- How the substorm growth phase relates to changes in the interplanetary medium
- How onsets of each substorm are produced
- How a substorm is affected by previous substorms
- Whether quiet times consist of ongoing successions of very minor substorms
- Whether increases in the kinetic energy content of the ring current occur primarily during the growth or the expansive phases of the substorm
- Whether the substorm concept needs to be expanded to account for complexities not now generally recognized.

Essential components of the MAMOS required to attack these problems meaningfully are the manned observatory, which will remain attached to the Shuttle Orbiter, and a relatively complex unmanned sub-satellite, which will be placed into a higher orbit. These are illustrated in Figure 6. The main observatory is to be placed into a polar orbit approximately oriented along the noon-midnight meridian. The nominal period of such an orbit is 100 minutes. The launch is to be during the northern solstice period so that maximum darkness occurs over this hemisphere. It is to be timed so that the observatory passes from the dark side of the earth to the northerm polar region.

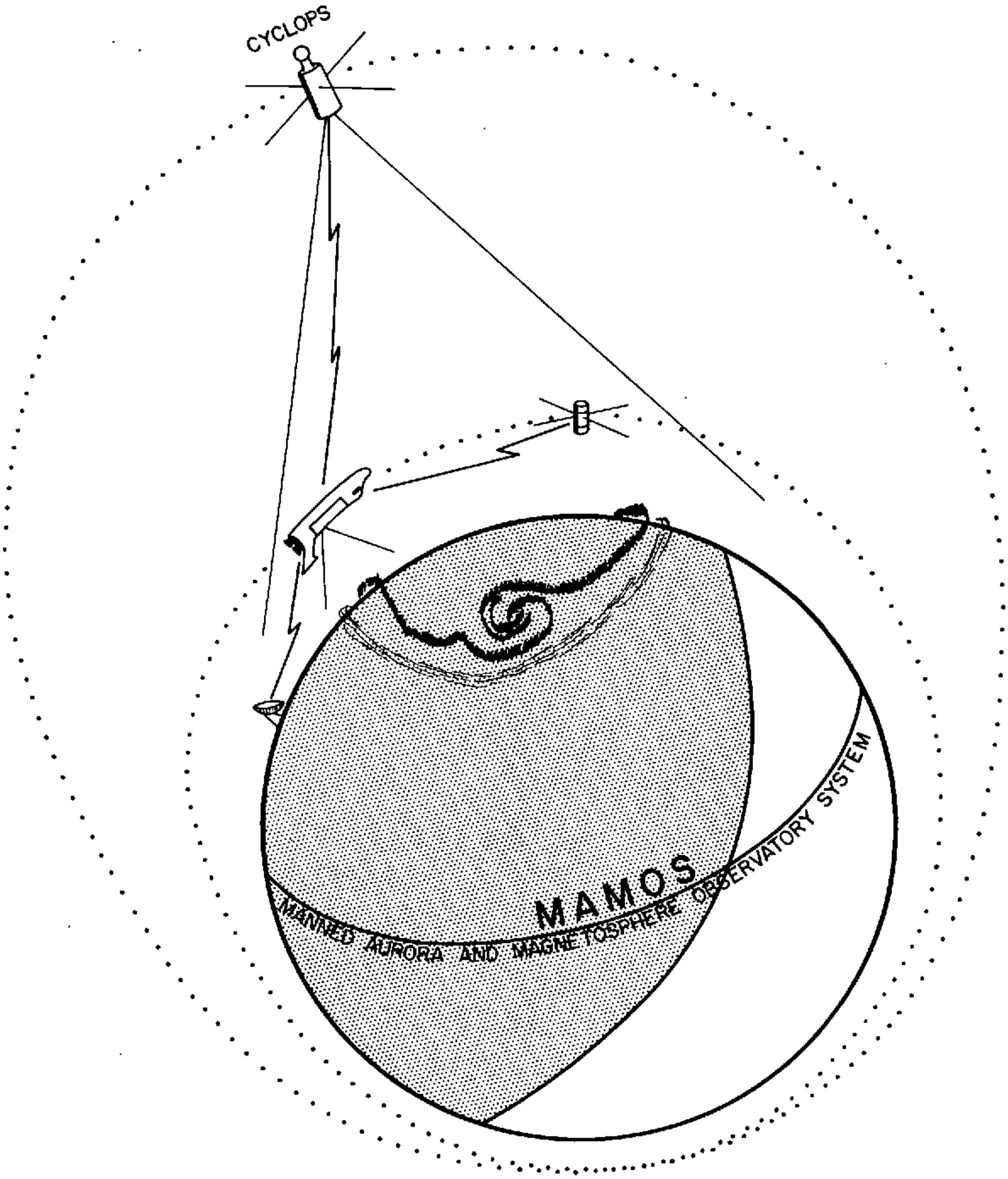


Figure 6. Manned Aurora and Magnetosphere Observatory System

Once the main observatory is in orbit, the smaller, unmanned, observatory (the major sub-satellite described on page 40) is to be launched from it into a highly elliptical orbit in the same plane as the main observatory. It is to have an apogee that causes the period of its orbit to be several times that of the main observatory. Thus, each third or fourth polar pass of the main observatory will occur when the sub-satellite is over the polar region. The primary purpose of the secondary satellite is to acquire imaging observations of the hemispherical auroral distribution during the two hours or so of each orbit when the secondary observatory will be above latitude 60°.

Instrumentation aboard the secondary satellite will include the following:

- A redundant imaging system to view the entire auroral oval
- A vector fluxgate magnetometer and a triaxial search coil for magnetic measurements
- Long-boom electric field probes for measuring D.C. and A.C. electric fields
- Detectors to measure low- and medium-energy electrons and protons (5 eV to 100 keV)
- Instruments to measure thermal plasma and ion composition.

Instrumentation carried aboard the main observatory will be more complex, and, since the observatory will be manned, it can be more versatile. For auroral observations, an array of imaging and scanning systems will be carried, probably on the gimbaled platform core instrument (see page 39). One of the most important of the imaging systems will be one that has a narrow ($\sim$5-10°) field of view pointed down the direction of the magnetic field so as to observe auroras on the magnetic field line occupied by the main observatory. Other imaging systems with fields of view up to 140° will allow observation of auroras within 1500 km of the observatory. These systems will be provided with a variety of filters and operating modes to be chosen by the scientific crew as conditions warrant. A significant task of the crew will be to maximize the operation of these instruments.

Other instruments of main importance for relating measurements of various parameters to the aurora must have adequate time resolution to make this relating worthwhile. With its velocity of near 7.5 km/sec, the main observatory will pass through an auroral structure of thickness 100 m in 17 msec. Hence sampling rates should match or exceed 60 per sec. Since it is desirable to make extensive observation of electron and proton fluxes with high resolution in pitch angle and energy, a large array of particle detectors should be carried. Vector magnetometers and search coils for the study of field-aligned currents and waves and for other purposes will be carried on a long boom assembly (see page 36) as will electric field probes samples to determine the D. C. and A. C. electric field, and a variety of probes for the measurement of thermal and very low energy plasmas. Particular emphasis should be placed on measurement of upward and downward fluxes. One of the most desirable measurements is of ion and neutron composition; thus, several spectrometers may be carried for this purpose.

The weight-lifting capability of the Shuttle and its ability to carry a scientific crew allows the possibility of carrying additional heavy and complicated instruments to explore the plasma characteristics of the polar and auroral regions. Thus, electron and ion accelerators (page 39) will be carried for use in studying the interaction of controlled beams with the atmosphere and the lengths of paths over which electrons travel from hemisphere to hemisphere. It is likely that the observatory will also carry one or more downward-directed lasers (page 42) to measure the density of certain constituents of the upper atmosphere as a function of altitude and latitude. Also, it will be possible to carry a large number of small shaped-charge devices (page 39) that can be spring-ejected and then detonated to produce barium and other releases for the purposes of field-line tracing, electric field mapping and, perhaps, environmental modification.

A scientific crew of two to four personnel, and missions of at least seven days duration are desirable. Scientific crew activities envisioned are:

- Checkout and maintenance of equipment
- Operation of remote-sensing and active instruments
- Communication with ground-based scientific personnel
- Repair of malfunctions
- Performance of onboard data reductions to maximize the efficiency of spacecraft-to-ground data transmissions.

RELEVANCE OF THE PLANNED SCIENTIFIC PROGRAM TO OTHER DISCIPLINES

The scientific program attainable with the core instrumentation and the candidate payload concepts described in the previous sections includes a very major part of the needed research in Atmospheric and Space Physics which the Working Group is able to visualize at this time. It includes a program that could usefully occupy the talents of a large portion of the scientific community for perhaps a decade or more. However, since no part of proper science is insulated from other parts, or from eventual practical applications, it is useful to review the areas in which these particular fields of endeavor relate to the larger problems of our time.

A major area of growing interest in atmospheric and space physics is the generation and propagation of electromagnetic waves in space and their interaction with the ambient plasma medium, the ionosphere, and the atmosphere. If we fully understood all the relevant wave phenomena, we might, for example, be able to describe unambiguously the mechanism by which energetic charged particles enter and leave the earth's magnetosphere. Hopefully, this would lead to an ability to predict world-wide magnetic storms and auroral substorms. Thus, storm-induced power failures in high-latitude electric utility lines in the United States, Canada, and other parts of the world — such as occurred during the large magnetic storm resulting from the solar flare of August 1972 — could be sharply reduced. The exciting possibility of triggering such activity at will is also tantalizingly before us, but must await the outcome of the definitive work which will provide us with the detailed understanding without which this is merely a speculation.

If we could understand how auroras are formed, what the acceleration mechanisms are to produce these natural nearly monoenergetic beams of electrons; if we could understand how the auroral source particles drift into the magnetosphere and remain trapped there until the substorm releases them, it would be a great aid in solving the much-researched laboratory problem of confining and controlling a hot plasma. Similarly, the plasma information gleaned from a study of hydromagnetic resonances using the large MHD wave generators which can be accommodated on the PPEPL or the MAMOS, and the study of coulomb collisions in the upper atmosphere through use of electron and ion beams artificially produced in space, will provide fundamental insights into laboratory plasmas and the myriad of instabilities which make control of hot plasmas so difficult.

Better understanding of the space plasma instabilities may make it possible to fill or empty geomagnetic tubes of flux at will. It may also make possible the control of some types of ionospheric disturbances. The MHD-generation devices and charged-particle acceleration devices on the PPEPL will be conducting active experiments along these lines. If successful, not only could ionospheric communications be improved, but the ominous specter of radioactive fallout could be eliminated, permitting us to dump large volumes of trapped radiation over global regions where no harm will result, or to dissipate safely what are otherwise dangerously large concentrations.

World-wide communication should be immensely aided by our efforts in these Sortie laboratories to explore the limits of dumping in the magnetoplasma. This is true of both the limits of MHD and electromagnetic wave energy which can be made to fill a small region of the magnetosphere and the limits of thermal plasma injection of lithium, barium, and other chemicals. The possibility of using geomagnetic field lines as waveguides for signals from earth to a spacecraft, or from a spacecraft to earth, or to submarines, can be explored in detail. Similarly, the possibility of using low-frequency MHD waves to communicate from space to stations under water can be explored with the high-power, long wavelength antennas on board the PPEPL.

One of the uses of the Shuttle Laboratory will be to inject test quantities of various types of gases into the upper atmosphere. The effects of solar ultraviolet light can then be studied directly through their resulting fluorescence. Such experiments, together with other observations planned on the ASF and MAMOS, will provide knowledge of the solar UV environment in the upper atmosphere and its secondary and tertiary effects on the atmospheric processes below. Such information is critical to the design of safe passenger compartments for high-flying commercial aircraft such as the supersonic transport. In a like vein, observations of the spread of test gases released from the Sortie laboratories will provide information for the study of the dissipation of contaminants in air pollution, the speed of the dissipation, the dependence on molecular species, and so forth. In the reverse operation, observation from space of the generation and spreading of air pollution from ground-based factories is a means of determining air circulation patterns in both the lower and the upper atmosphere. A good working knowledge of the global vertical and horizontal circulation patterns, and their dependence on the solar input function, will, in its own right, point the way to minimizing the adverse effects of factory and urban pollution by aiding in more intelligent choices of factory locations and working hours.

Hopefully, the Shuttle Laboratory, in broadening our understanding of upper atmosphere dynamics, and in extending our understanding of the effects of the fluctuating solar input to ever lower altitudes, will take a giant step towards the merger of upper atmosphere sciences with the science of meteorology, which merger is a necessary prelude to any useful program of long-range weather forecasting. At present, we have no available means for continuous mapping of either lower-space or upper-atmosphere global circulation patterns. The techniques developed by the Atmospheric and Space Physics Laboratory should be a great aid in remedying this.

As a final note, the study of the atmospheres of other planets should be aided greatly by the test gas release experiments on the Shuttle. Some of the releases will be of the components of other planetary atmospheres, as well as of components of the early terrestrial atmosphere, so that questions of the solar effect on evolutionary processes can be studied in a natural, wall-free environment.

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